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ON THE CLASSIFICATION

OF THE

EARLY CAMBRIAN AND PRE-CAMBRIAN FORMATIONS

BY

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EARLY CAMBRIAN AND PRE-CAMBRIAN FORMATIONS.

A BRIEF DISCUSSION OF PRINCIPLES, ILLUSTRATED BY EXAMPLES DRAWN MAINLY FROM THE LAKE SUPERIOR REGION

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THE PROBLEM STATED.

The following paper owes its existence to the necessity felt by the writer of having clearly defined principles upon which to proceed in revising the various classifications that have been proposed for the ancient formations of the Lake Superior region or in substituting for them some entirely new arrangement. Beyond many of the facts cited in illustration and the mode of presentation, the paper does not contain very much that is new or original; nevertheless, that a necessity exists beyond that of the writer for a clear apprehension of the principles here set forth will become evident to any one who studies carefully many of the more recent publications upon the early Cambrian and so-called Archæan formations.

The problem proposed for discussion is this: Having established in a given region occupied by the oldest non-fossiliferous and meagerly fossiliferous formations the general order of succession: (1) to determine upon the grander divisions (groups) to be made in classifying the rocks independently of their relations to the general geological column; (2) to extend these divisions to other portions of the same geological basin; and (3) to correlate these divisions with those of different and distant geological regions. This is the problem which presents itself in the Lake Superior region, at the base of the Grand Cañon of the Colorado, in central Texas, in Newfoundland, and in other portions of North America.

In any attempt to solve such a problem we can make use of one or more of three kinds of characteristics in the formations involved, viz, (1) their paleontological characteristics, (2) their lithological characteristics, and (3) their mutual structural relations. The considerations that follow are classified under these three heads, under each of which the discussion is further arranged with reference to the three divisions of the problem indicated in the preceding paragraph.

PALEONTOLOGICAL CHARACTERS AS A BASIS FOR CLASSIFICATION.

The general principles of homotaxis and of the use of fossils in classifying formations are not here under discussion. It is proposed rather, supposing a region with the general conditions above stated, to consider how such fossils as are found may be used in marking off from one another the grander groups of strata, how far they may be used in recognizing these groups at other points in the same geological basin, and how far they may be used in correlating these groups with those of the general geological column.

The use of fossils in determining the grander groups of strata.—The object being particularly to avoid extending conclusions to an unwarrantable extent, the discussion is mainly taken up with precautionary considerations. The general order of life succession in geological time appears to have been sufficiently well established to allow the use of the differences between well developed and varied faunas in marking off the grander divisions of strata and the use of their similarities in grouping together strata for whose separation there might otherwise be an apparently sufficient reason. But when we have at our service but fragmentary faunas or single fossils we need to be very cautious indeed in drawing our conclusions. We have now constantly to remember that paleontology is based wholly upon stratigraphy, and consequently that the conclusions that we would draw from our fossils must constantly be checked by stratigraphical observations. We must equally remember the well established principles that fossil kinds vary at the same stratigraphical horizon with variations in the kind of rock and that the same fossil may return with rock of a similar character at horizons vertically far apart. But, most of all, we need to bear in mind the negative character of the evidence upon which the range of a given fossil is determined. Past experience in the discovery of fossils far above or below, or both above and below, the limits of the range laid down for them in the text-books should be sufficient to caution us against drawing too confident conclusions from meager fossil evidence, particularly with fossils which, while of relatively limited range as to certain specific characters, are yet so closely allied to other kinds as to form with them a general type prevailing throughout a great series of formations. Moreover, with the earliest fossiliferous formations, more than with any of those of later times, do we need to be cautious in generalizing on insufficient paleontological data. These formations are not only meagerly fossiliferous, but such fossils as they carry are very generally of types which have a wide range upward through the geological column. An equally wide range for them downward, among those formations which have not yet yielded fossils or which are yet to be met with in unexplored portions of the world, may reasonably be inferred. It

has been the history of progress in paleontological geology that the advance of discovery has been downward. It is but a short time since the so-called Cambrian formations were thought to be unfossiliferous. Below these, in various other portions of the world, are other formations in which no fossils, or only bare traces of fossils, have as yet been discovered, but which have about them no characters which would exclude the possibility of such a discovery in the future.

An illustration drawn from the region with which the writer is more particularly familiar may serve to give the foregoing considerations a more definite meaning. The lowest well defined fossiliferous horizon in the northwestern States of Michigan, Wisconsin, and Minnesota is the Cambrian sandstone, regarded by the best authorities as the equivalent of the Potsdam horizon of the New York reports. Unconformably placed below this sandstone is a succession of three great groups of formations of enormous volume, each separated from its predecessor by a great unconformity. The lowest one of these three groups is a gneissic and generally a highly altered one. The other two, however, have nothing about them to exclude the possibility of the future discovery in them of fossils. In the upper one of these groups, two obscure and indefinite markings have indeed been discovered, but as yet nothing more. In a remote corner of the region in question, however, is a quartzite formation which is also manifestly unconformably placed beneath the fossiliferous Potsdam horizon and equally unconformably above the lower gneissic series. It thus falls somewhere in the interval occupied by the two groups above spoken of as lying next beneath the Potsdam horizon; but its connection with either of these groups is concealed for many miles by overlying terranes. In this quartzite series have been found impressions of a linguloid fossil and a single fragmentary specimen of very questionable organic origin,[1] which has been doubtfully referred to the genus *Paradoxides*. Upon this evidence has been based the conclusion that the formation holding these fossils, while lower than the fossiliferous Potsdam sandstone, should yet be thrown into the same grand division with it, and that all of the upper (Keweenaw series) and much, if not all, of the lower (Huronian or iron-bearing series) of the two groups (which, as above stated, in other portions of the northwest intervene between the Potsdam sandstone and the gneissic series) should be thrown into the same group.

The argument in favor of these conclusions appears to be about as follows: In other portions of the world the fossil-bearing strata beneath the Potsdam horizon are classed with that horizon as Cam-

[1] The organic nature of this fossil is denied entirely by Mr. C. D. Walcott, paleontologist of the U. S. Geological Survey, who gives his opinion after sectioning and carefully studying the original specimen; but its possibly organic nature is assumed here for the sake of argument.

brian, being conformably placed beneath it and having, in general, fossils of the same types. Here are two fossils of types found in the infra-Potsdam fossiliferous rocks of other regions; therefore this formation also should be classed with the Potsdam in one group as Cambrian. The objections to be made to this argument are (1) that, of the few fossils concerned, the linguloid kinds are of so great a known range upward that an equally great range for them downward may reasonably be inferred; (2) that the vertical range of the doubtful *Paradoxides* is determined by negative evidence only; (3) that, nothing whatever being known of the Pre-Cambrian life beyond the necessary conclusion that such life must have existed, there is no inherent improbability that it included linguloid and trilobitic kinds not greatly dissimilar to those of the true Cambrian; and finally (4) the conclusions are objected to because such weak paleontological evidence is allowed to overcome the counter-evidence of at least one and probably two unconformities indicative of great time gaps. The general significance of unconformities and their value in determining the limits between grand geological groups is further discussed below.

The use of fossils in establishing correlations within one geological basin.—The succession of strata having been determined for one portion of a given geological basin, i. e., of an area within which the various formations are or once were essentially continuous, the faunas respectively characteristic of the several strata are, of course, of the greatest value in establishing the grander correlations with the stratal successions in other portions of the same basin, provided, however, that the faunas are fully developed, each including a number of well characterized forms. Even in such a case, however, paleontologists are often prone to push their conclusions too far in establishing correlations in more minute detail, losing sight of the negative nature of the evidence on which the ranges of the several fossils are based, and more particularly of the influence upon the occurrence of fossil forms of slight changes in the nature of the rock. All later investigations teach us to beware of such minute correlations, even within short distances, the fossils characterizing a certain horizon disappearing above it to return again with a return of like mineral conditions, which are themselves indicative of the return of geographical conditions favorable to that particular life development. Much is said of the worthlessness of lithological evidence in establishing correlations and in tracing formations, but, except in the case of the grander correlations, and particularly for places distantly removed from one another, it is much of the same nature and value as paleontological evidence. In using either to trace formations from place to place we must constantly check by stratigraphy. It is, indeed, an exceptional region where layers of rocks can be seen in continuous exposure. Their continuity is es-

tablished by the discovery of similar successions of strata having similar lithological characters at numbers of points all through the distance through which it is desired to establish the continuity. Fossils may occur to confirm greatly the conclusions reached without them, but alone they are of no more value in tracing continuities of the minor subdivisions than is the lithological evidence. Both the lithological characters and the fossils of a stratum may change somewhat as we trace the layer from point to point.

The use of fossils in establishing general correlations.—But, if paleontological evidence needs to be used cautiously when we have at command fully developed faunas, how much more cautious do we need to be when any or most of our formations are barren in fossils or contain at best a few obscure forms of doubtful range. Again, if limited fossil evidence is to be used with such caution in differentiating the grander rock groups of a region and in correlating the stratal successions of different parts of one geological basin with one another, how much more must we be careful in applying such meager evidence to the grander correlations of the ancient formations of one region with those of another and distant region and with the generally recognized great groups of the geological column.

The necessity for this caution and the nature of the questions that arise will be best understood if I take as illustrations the case of the region above cited and the very similar case of the formations met with in the bottom of the Grand Cañon of the Colorado. In each of these cases we have the Upper Cambrian clearly defined by its characteristic assemblage of fossils. In each region there intervene between this Upper Cambrian horizon and the basement gneiss two great groups of strata, which are divided from the Upper Cambrian above and from the gneiss below by great unconformities, and are, moreover, separated from each other by an equally great discordance. In each region, again, while mainly unfossiliferous, these intervening strata have afforded very scant traces of life. In the case of the Grand Cañon, these traces, in the shape of a few obscure and ill defined linguloid brachiopods, occur in the group next beneath the unconformity below the Potsdam or Upper Cambrian horizon. In the case of the region of the Northwestern States, the fossils found are the linguloid forms and the more than doubtful *Paradoxides* above mentioned, which are met with at a single locality in a formation that certainly lies in the interval between the Potsdam horizon and the gneiss, but is less certainly referred to the lower one of the two formations belonging in this interval—a doubt arising from the isolated position of the formation in question.

Now, in other portions of the world—for instance, in New Brunswick and Newfoundland, in North America, and in Wales and Bohemia, in Europe—are found, conformably placed beneath the Upper Cambrian horizon, great thicknesses of strata, each with a well devel-

oped and characteristic fauna of its own, constituting the Middle Cambrian and Lower Cambrian faunas. Are we to conclude, then, from the few fossils met with in them, that the Pre-Potsdam formations of the Northwestern States and of the Colorado Cañon are necessarily wholly or in part geological equivalents of the formations which in other parts of the world carry these faunas? Such a conclusion appears, to me at least, quite an unwarranted one. As stated above, the few fossils found, while such as might occur in a Lower Cambrian fauna, are yet kinds belonging to types of so great a known vertical range as to suggest their probable occurrence at much lower horizons than those of the Lower Cambrian. That a Pre-Cambrian fauna existed goes without saying, while the probability that this fauna had affinities with that of the Cambrian itself is certainly suggested by the analogy of all the later formations. Moreover, should we accept such a correlation, we are compelled to belittle a great time gap indicated in both these regions by the unconformity below the Potsdam horizon. Such unconformities as this, as is urged more fully below, must indicate long continued and geographically widely extended orographic movements followed by periods of denudation of immense duration. They cannot be dismissed as merely local phenomena.

Should we decide, however, that in these lower, unconformable formations we have to do with rocks older than those which elsewhere carry the primordial fauna, we are immediately confronted with the question as to whether they too, because of the few fossils they carry, should still be classed as Cambrian. This is merely a special phase of a much broader and, as yet, undecided question in geological taxonomy. As the geological column now stands, the grand divisions of Cambrian and Archæan are next to each other. Above the uppermost Archæan, however, and below the lowest of the Cambrian fossil horizons, we have in various portions of the world formations whose characters are in no way such as to preclude the possibility of the discovery in them of fossil remains. Moreover, a belief in the existence of life during the times when these formations were accumulated being apparently a theoretically necessary one, the history of the advance of paleontology would certainly lead us to look for such discoveries. Discoveries of such a character have, indeed, been made already; for, not to speak of the fossil finds in the Grand Cañon group of the Grand Cañon and in the quartzites of southwestern Minnesota—which formations, from my point of view, both belong beneath the formations holding the Lower Cambrian fauna—we may cite the case of the occurrence of fossil markings in that great formation of Newfoundland which has been called Huronian by the late Mr. Alexander Murray. Above these fossiliferous Huronian rocks and separated from them by an immense unconformity, the reports of Mr. Murray inform us that there comes,

not merely the Upper Cambrian horizon, as in the case of the Colorado Cañon and of the Lake Superior region, but an enormous thickness of strata with the Lower Cambrian fauna. The question then is this: As we reach deeper and deeper into these formations are we to keep extending the term Cambrian downward with these discoveries, leaving as Archæan only those formations which are as yet not proved to hold fossils? The question thus stated leads us in turn to a yet broader one, viz, as to the relations between the terms Paleozoic and Archæan. Answers to these questions, which are quite distinct from one another, are attempted in the latter part of this paper.

LITHOLOGICAL CHARACTERS AS A BASIS FOR CLASSIFICATION.

The use of lithology in marking off the grander groups of strata.—Setting aside those cases where rocks have been in one way or another deeply altered, variations in lithological characters among sedimentary strata are indicative of original differences in methods of deposition, while similarities of lithological characters indicate, in general, similarities in conditions of deposit. Similar rocks recur again and again at different points in the geological column and are indicative of the repeated return of similar depositional conditions.

Such returns occur frequently within a single group of formations and are of value in establishing the minor subdivisions of the group, but, without other strong evidence, they are of but little more than confirmatory value in separating groups from one another. Looked at in a general way, juxtaposed groups of strata, it is true, often show strong contrasts in lithological characters. But, on the other hand, they may show very considerable similarities, while structural or paleontological evidence may demonstrate their complete separateness. As an instance of this may be cited the case of the Potsdam sandstone and the Keweenaw series of Lake Superior. The upper 15,000 feet of the Keweenaw series are composed of sandstones which in general aspect often simulate the members of the Potsdam itself, though closer inspection shows generally strong lithological differences. On account of this general similarity, however, these two sets of sandstones, demonstrated by their structural relations to belong to totally distinct systems of strata, were constantly connected in one group by the earlier writers on the Lake Superior region.

Nevertheless, contrasts in the lithological characters of two series of strata, when these contrasts are the result in any large measure of a deep-seated alteration of the lower one of the two series, may constitute evidence of a high degree of value as to their distinctness, although, even in this case, such evidence would be subordinate in value to the paleontological and structural data. As an illustration we may cite, in the first place, the case of lithological contrasts which obtain in the Lake Superior country between the ancient gneissic

group and the iron-bearing or Huronian group. The term Huronian, as is shown subsequently, has no doubt been applied frequently to quite distinct formations, but is here restricted to that group which, on the north shore of Lake Huron, in the Marquette and Menominee regions of Michigan, in the Penokee country of Wisconsin, and in the region north of Lake Superior, sustains a plainly discordant relation to the more ancient Laurentian, or crystalline schist and gneiss series. The gneissic series is composed of granites, strongly crystalline gneisses, and schists which very rarely present unmistakable evidence of a sedimentary origin and which in all cases, whether originally of sedimentary, of eruptive, or of some wholly unknown origin, have been subjected to most profound changes. The Huronian, or iron-bearing series, on the other hand (not to speak now of those eruptives which it includes and which present us with no serious difficulties in their recognition as such), is plainly made up of fragmental rocks, usually differing but little from those of later geological groups, and of certain sediments of a chemical origin. In all of these the only changes that have taken place are clearly of a metasomatic character, and each altered rock, whether of mechanical or chemical sedimentary origin, can generally be traced back without difficulty to the unaltered form.

The use of lithological characters in establishing correlations between different portions of the same geological basin.—Lithological characters have their greatest value to the stratigraphical geologist in his attempts to establish such correlations as are indicated in the heading of this paragraph. After having defined the several rock groups from one part of a single geological basin—that is, a region throughout which the various rock groups are, or once were, essentially continuous—and having established the lithological characters of each group, the geologist, with the greatest confidence, makes use of these characters in tracing the several groups to other portions of the basin. He does not ordinarily go from one end of the region to the other before making comparisons, but, beginning with the portions best known, he traces mile by mile the several groups by means of their lithological characters and stratigraphic relations. It is customary to speak very contemptuously of lithological evidence, and there can be no question that it has been used as a foundation for conclusions which it certainly cannot support. But its value in tracing formations from point to point can hardly be overestimated, being as great as that of paleontological evidence and, in my judgment, of much the same nature. As we trace formations and their minor subdivisions from place to place we must of course constantly check lithological evidence by stratigraphy. As we pass from one extremity of the field to the other, changes in lithological characters of course come in, and these changes might lead to unsafe conclusions were we to compare stratal successions

too distantly removed from one another; but when we work from point to point such changes are detected as they gradually appear, and are provided for. Now, precisely the same statements can be made with regard to the use of fossils in tracing formations. Equally with the lithological characters do the paleontological characters of a formation change as it is traced from point to point. Indeed the changes are often more abrupt in the latter case.

The Lake Superior region furnishes some admirable instances of the value of lithological evidence, both in tracing the grander divisions of the strata and in establishing correlations between the minor subdivisions of the successions displayed in different portions of the region.

In the Penokee region of Wisconsin, as is set forth somewhat fully on a subsequent page, there is a succession of formations whose relations are quite unmistakable. Lowest in this succession is a great series composed of gneiss, granite, and green schists. Resting unconformably upon the deeply denuded surface of this series is the great iron-bearing group of strata, thirteen thousand feet and upwards in thickness, while upon the eroded surface of this group succeeds, in turn, the great Keweenaw group, with an aggregate thickness of 45,000 feet, through the lower 30,000 feet of which alternate eruptive and detrital layers, the uppermost 15,000 feet being wholly detrital. All of this succession of layers above the upper surface of the gneissic series presents us with a dip to the north, or in the direction of Lake Superior. Passing now to the northern side of the western part of Lake Superior we find again a similar succession, now with a southerly dip. A section along the line of the newly built Duluth and Iron Range Railroad from the Mesabé Range, 55 miles north of Lake Superior, to the shore of Lake Superior, would show to the north a formation of gneiss and granite, unconformably reposing upon which is an iron-bearing formation that, so far as it appears at the surface, is quite identical in character with that of the Penokee region, while above this again comes the great Keweenaw series, or rather its lower portion, for its uppermost portions are concealed beneath the waters of Lake Superior. That the several formations of this succession are identical with those of the Penokee region is so manifest from their lithological characters and structural relations alone that the abundance of other evidence that presents itself as to the actual continuity of the formations of the two districts is hardly necessary for a conclusion. Returning again to the south shore of Lake Superior and extending our investigations eastward from the Penokee region as far as the vicinity of Marquette and the Menominee River, we trace all the way from the former district the gneissic terrane and its unconformably overlying, iron-bearing series. But after leaving Lake Gogebic we find that the uppermost of these terranes, instead of being simply inclined

toward the north without folding, has been more or less deeply folded in with the basement or gneissic series in such a manner that, as a consequence of the profound denudation that has since ensued, it appears now at the surface in more or less regular belts or in quite irregular patches within the area of the older rocks. But the lithological evidence as to the continuity of each of the two series is indisputable. In a similar manner we might proceed from the Marquette region to the north shore of Lake Huron and thence again to the northern coast of Lake Superior, eastward from Thunder Bay, and show that in each of these regions there exists the same succession of gneissic formation, iron-bearing formation, and Keweenaw series, each bearing the same structural relations to the others as in the regions previously mentioned, the lithological characters of each demonstrating its identity with the corresponding member of the successions in other districts.

As an illustration of the value of lithological evidence in establishing the continuity of the minor subdivisions of a great group of strata we may cite the case of the Nonesuch shale and sandstone beds of the Keweenaw series, which beds are now known to be continuous from midway in the length of Keweenaw Point to Bad River in Wisconsin, a distance of over one hundred and fifty miles, following the course of the outcrop.[1] This continuity is established beyond controversy—notwithstanding the fact that in this distance the layer goes through a singular convolution in the vicinity of the Porcupine Mountains and notwithstanding also the generally forest-clad character of the region—by the recurrence at a number of points between the two extremities of the belt mentioned of the same peculiar strata in a similar position with reference to the other layers of the series. Again, the comparison of the Penokee series with the iron-bearing formations of other districts of the Lake Superior region enables us to say that the iron-bearing horizon of the Penokee district is the equivalent of the iron-bearing horizon of the Animikó district on the north side of Lake Superior, and again of the iron-bearing horizons of the Marquette and Menominee regions, and that the great limestone and quartzite formation below the iron-bearing series in the Penokee region is the same that receives so great a development below the iron-bearing horizon of the Marquette and Menominee regions. While there are very numerous points in the stratigraphy of these several districts as to which sufficient data have not yet been accumulated to enable us to make satisfactory comparisons, it is confidently expected that it will not be long before such comparisons can be greatly extended.

The use of lithological characters in establishing correlations between the stratal groups of different geological basins.—Inasmuch as the lithological characters of rocks are independent, under any or-

[1] See Mon. U. S. Geol. Survey No. 5, 1883, pp. 193, 199, 200, 221–224, 226, 230, 231.

dinary circumstances, of times of deposit, having resulted from the original conditions of deposit, similar conditions having produced similar rocks, and since the same conditions have recurred again and again in geological time, while dissimilar conditions, in different regions of deposit, must have coexisted at all periods as they now coexist, it is a well founded and generally accepted canon of the geological science of to-day that similarities in the geological formations or groups of different regions of rock growth are of no value as proofs of equivalency, at least so far as all of the fossiliferous formations are concerned. It is recognized, of course, that there are certain horizons in the geological column which are represented in portions of the world distant from one another by formations quite singularly like one another, as is the case, for instance, with the "New Red Sandstone" horizon. But such coincidences as these are regarded as accidental. It is also recognized that the more ancient of the fossiliferous groups present a more widespread uniformity in lithological characters than is found to be the case with the later groups; but this is generally taken as indicating merely the greater extent of the earlier geological basins, that is, of the individual regions of rock growth, the continental surfaces having been less thoroughly differentiated by the elevation of mountain barriers. Neither of these well recognized facts is taken as invalidating in any measure the general truth of this canon so far as the fossiliferous formations are concerned.

When we turn, however, to the writings of those who have concerned themselves with the Pre-Paleozoic formations we find this principle very generally ignored, while a few authors distinctly deny the validity of its application to those ancient formations.

The latter view is held by a small class only, but has able exponents both in this country and in Europe, the most thoroughly elaborated and advanced position being held by Dr. T. S. Hunt, in whose later writings there is maintained a division of the Pre-Paleozoic formations into the following groups given in ascending order, viz: (1) The ancient *Laurentian* granites and granitoid gneisses; (2) the *Norian* feebly silicated, plagioclastic rocks; (3) the *Arvonian* felsites, quartziferous porphyries, etc.; (4) the *Huronian* chloritic greenstones and chloritic schists; (5) the *Montalban* micaceous gneisses and mica schists; (6) the *Taconian* quartzites, limestones, and argillites; and (7) the *Keweenian* series of Lake Superior. With the exception of the last of these, which appears to be considered as Paleozoic, though placed in its true relation to the Cambrian, all of these groups are spoken of as composed of crystalline rocks. While some doubt appears to be expressed as to the exact relation of the Norian to the Laurentian and the Huronian series, the succession as given is taken as essentially true for the entire extent of the globe, each group being regarded as separated from its predecessor by an

intervening land surface period or period of disturbance. As to the origin of the rocks of these several crystalline rock formations the opinion held by this school will be best expressed in Dr. Hunt's own words:

The crenitic hypothesis, which has been proposed in the second part of this essay to account for the origin of the granites and crystalline schists, conceives them to have been derived, directly or indirectly, by solution from a primary stratum of basic rock, the last congealed and superficial portion of the cooling globe, through the intervention of circulating subterranean waters, by which the mineral elements were brought to the surface. This view not only compares the generation of the constituent minerals of the primitive rocks with that of the minerals formed in the basic eruptive rocks of later times, but supposes these rocks to be extruded portions of the primary stratum which, though more or less modified by secular changes, still exhibited after eruption, though on a limited scale, the phenomena presented by that stratum in remoter ages (Proc. Trans. Royal Soc. Canada for 1884, vol. 2, "The origin of crystalline rocks," p. 36).

The crystalline stratiform rocks, as well as many erupted rocks, are supposed to have been derived by the action of waters from a primary superficial layer, regarded as the last portion of the globe solidified in cooling from a state of igneous fluidity. This, which we have described as a basic, quartzless rock, is conceived to have been fissured and rendered porous during crystallization and refrigeration, and thus rendered permeable to considerable depths to the waters subsequently precipitated upon it. Its surface being cooled by radiation, while its base reposed upon a heated solid interior, upward and downward currents would establish a system of aqueous circulation in the mass, to which its porous but unstratified condition would be very favorable. The materials which heated subterraneous waters would bring to the surface, there to be deposited, would be not unlike those which have been removed, by infiltrating waters in various subsequent geological ages, from erupted masses of similar basic rock, which, we have reason to believe, are but displaced portions of this same primary layer. The mineral species removed from these latter rocks or segregated in their cavities are, as is well known, chiefly silica in the form of quartz, silicates of lime and alkalies, and certain double silicates of these bases with alumina, including zeolites and feldspars, besides oxyds of iron and carbonate of lime, the latter species being due to the intervention of atmospheric carbonic acid. The absence from these minerals of any considerable proportion of iron-silicate, and, save in rare and exceptional conditions, of magnesia, is a significant fact in the history of the secretions from basic rocks, the transformation of which under the action of permeating waters has resulted in the conversion of the material into quartz and various silicates of alumina, lime, and alkalies, while leaving behind a more basic and insoluble residue abounding in silicated compounds of magnesia and iron-oxyd with alumina (ibid., pp. 58 and 59).

We have already elsewhere in this essay * * * referred to the local development of crystalline silicates in sedimentary rocks by infiltration, and have, in another place, considered the relation of such a process to the question of the origin of primitive crystalline rocks. These we believe to have been formed anterior to the existence of detrital sediments, and by a process which excludes alike all so-called metamorphic, metasomatic, and plutonic hypotheses of their origin. At the same time we reject the Wernerian or chaotic hypothesis, and its modification by De La Beche and Daubrée, which we have called thermochaotic, in favor of a new aqueous or neptunian hypothesis, which supposes the elements of these rocks to have been dissolved and brought to the surface from a disintegrated layer of igneous basic rock, the superficial and last-solidified portion of a cooling globe, through

the action of circulating waters. The soluble and insoluble products of the subaërial decay, alike of igneous and aqueous rocks, are, however, supposed to have intervened in the process, especially during the period of the later crystalline or transition rocks (ibid., "The Taconic question in geology," p. 149, § 194).

The hypothesis thus defined is essentially a chemical one, demanding a certain universal and invariable order in the production of the various members of the Pre-Paleozoic groups. It is not, of course, maintained that every member of the succession must invariably be present. As in the case of later formations, so here also, the intervention of elevatory movements producing land surfaces, which receive no depositions, has produced gaps in the series. The order, however, is invariable. The conclusion then is drawn that the mineralogical character of a group of Pre-Paleozoic strata is a sufficient guide for us in establishing its place in the series; granites and granitoid gneisses wherever found are Laurentian; rocks composed mainly of anorthic feldspar and an augitic mineral are Norian; micaceous gneisses and mica-schists are Montalban; chloritic schists and greenstones are Huronian; quartzites, argillites, etc. are Taconian. The necessary corollary to the hypothesis, and one whose existence is thoroughly realized and whose truth is vigorously maintained by the distinguished leader of this school, is the complete rejection of the view, still held strongly by a large and authoritative school of geologists, as to the Paleozoic or even later age of certain of the crystalline schists.

Not attempting now to discuss this hypothesis from a chemical point of view, nor indeed in its applications to regions with whose geology I am little familiar or familiar only by reading, I will content myself by testing its validity by an application to that region with which I have had an extended and long-standing acquaintance, namely, the region from Lake Huron to Minnesota. Being of universal application, if valid at all, the facts in this region should coincide with the provisions of the hypothesis, whose failure to stand a single test of this kind should be sufficient for its rejection. Dr. Hunt, having visited various points of the Lake Superior region and having examined large collections from other points, has himself identified certain formations of the region as belonging to different members of his invariable succession, so that I shall be, in some measure, free from the danger of erroneous identifications.

Granites and granitoid gneisses indeed form an integral part of the basement formation of the Lake Superior region. With these, however, are great areas of garnetiferous and staurolitiferous mica-schist, which form, beyond question, inseparable portions of the same terrane, but which should belong to Dr. Hunt's Montalban group. Belts of such mica-schist are developed on an immense scale in the region of northern Minnesota, where are also great areas of granite, which, at their contacts with the mica-schist—contacts traceable for

scores of miles—invade these schists in the most intricate manner. Thus, granitic masses, which should belong to the Laurentian and on the crenitic hypothesis should be of aqueous origin, are found to be plainly eruptive and to intersect the Montalban schists. It should also be said that the gneisses of this ancient terrane appear to fall into two classes, one constituting a phase of the mica-schists and the other—granitoid gneisses—forming portions of the great granitic masses whose contacts with the mica-schists seem to demonstrate their more recent eruptive origin.

Equally forming an inseparable portion of the great basement terrane are areas and belts of greenish, chloritic schists. These are often closely associated with schistose greenstones, our microscopic studies having rendered evident, I think, the derivation of many of these magnesian, schistose rocks, by a process of metasomatosis accompanying and following intense lateral pressure, from augitic rocks analogous in all respects to the various augitic eruptives of later times, and particularly to the eruptives called gabbro and diabase. The relation of the greenish, chloritic schists to the mica-schists just mentioned is such as to render the later formation of the former probable; but there is a complete conformity between the two, while the great granite masses which send branches into the mica-schists present precisely the same relation to the chloritic schists, which at their contacts with the granite are often intricately intersected by granite veins. These green schists should be the Huronian of Dr. Hunt's succession. Indeed, they, with more or less of the mica-schists just mentioned, and with other later rocks, are what have been mapped as Huronian for the entire region north of Lake Superior by the Canadian Survey, whose more recent publications, however, assert with entire correctness the absence of any unconformity between them and the gneissic rocks called Laurentian. The name Huronian really belongs to an entirely different group, as is further noted below.

Similar greenish schists, similarly penetrated by granitic veins at their contacts with granitic masses, have a great development on the south side of Lake Superior, where, on account of the intricate foldings in certain portions of the region, they have been variously placed by different geologists. Some have divided them between the basement rocks and the iron-bearing group above them; by others they have been divided so as to come partly at the base and partly at the summit of the iron-bearing series; while others again have regarded all the greenish schists as forming the base of the iron series and the granites penetrating them as having been erupted at a period entirely subsequent to the deposition of the whole group of iron-bearing strata. But all, I think, as is more fully explained on a subsequent page, can be shown clearly to belong to the great basement series. Thus the large area of granite on the south or Wiscon-

sin side of the Menominee River, with which are associated hornblendic schists in such a manner as to render evident the later and eruptive origin of the granite, has been regarded by Brooks as the uppermost portion of the iron-bearing series, for the reason that the dip of the layers of that group farther north is slightly to the southward of vertical, or toward the granitic mass. But this granite and the hornblendic and micaceous schists associated with it are manifestly identical with the granite and schists on the opposite or northern side of the Menominee-Huronian trough, which have been counted by Credner, Brooks, and others as Laurentian. The inclination of the Huronian beds toward the southern granite is no argument in favor of its later date, being never more than a very few degrees beyond the vertical; while throughout the trough, as indicated in a section of the Menominee region given on a subsequent page, there is a tendency toward slightly overturned dips. Moreover the large exposure of greenish schists seen at the Upper and Lower Quinnesec Falls and at Sturgeon Falls of the Menominee River, which have been placed by Brooks and others in the Huronian, are quite plainly a portion of the older series, veins from the southern granite penetrating those schists also. The entire grouping of greenish, chloritic schists, greenstone-schists, hornblende-schists, mica-schists, and granites, the last penetrating all of the schists, is, then, precisely what is met with repeatedly on the north side of Lake Superior, as already indicated, and is met with repeatedly also in other places on the south side of the lake, where entirely similar rocks with similar relations have been placed as Laurentian by the same writers who would regard these Menominee granites and schists as a portion of the iron-bearing series. As to the position of these Menominee rocks in his classification we have Dr. Hunt's own determinations. The Quinnesec Falls and Sturgeon Falls green schists are his Huronian; the micaceous, hornblendic schists to the south of them, along with the granite which has such an immense development in that vicinity, are all Montalban.[1] In point of fact, however, all the schists concerned are but portions of a single succession, while the granite is of distinctly eruptive origin and more recent than any of them, all forming an inseparable part of the basement series of the Lake Superior region.

This same basement formation, with similar characters, is brought to view on the north shore of Lake Huron, where its contact with the overlying original Huronian group of Logan and Murray is displayed. The latter series consist of a great succession of quartzite layers, including a subordinate quantity of graywackes, often conglomeratic, and a much smaller proportion of limestone and chert, along with which are numerous intersecting and interbedded eruptive greenstones. The series is folded, but not strongly, the bowings being often so gentle that great areas occur in which the rocks are but

[1] Second Geol. Survey Pennsylvania, E, Trap Dykes and Azoic Rocks, p. 224.

little removed from horizontality.[1] The rocks of this series cannot be spoken of as deeply altered, their detrital origin being always manifest, except, of course, in the case of the limestones and cherts, which are of chemical origin, and the greenstones, which are eruptives. In large measure they differ but little in this respect from the rocks of some of the later and fossiliferous formations. Although this is the original and type Huronian series, the Huronian which does duty in Dr. Hunt's classification has no existence within the area referred to, i. e., that shown on Logan's beautiful detailed map of the north shore of Lake Huron.[2] Were we to apply Hunt's classification to this region we should have to regard the series here displayed as his Taconian.

As I have elsewhere argued and further show in subsequent pages of this paper, the iron-bearing formations of the south and north sides of Lake Superior belong with the original Huronian of the north shore of Lake Huron, like which they sustain an entirely unconformable relation to the underlying basement formation, and like which, again, they are composed of feebly altered rocks, mainly of detrital origin. Looked at as a whole, these formations would be, on Hunt's classification, plainly Taconian, to which position he has lately suggested that they should be assigned,[3] although he had previously spoken of the whole group as Huronian.[4] Nevertheless his studies of collections from these formations have led him to divide them among his Huronian and Montalban.[5]

The uppermost part of the iron-bearing series on the south side of Lake Superior shows generally a great development of a peculiar mica-schist or mica-slate which is associated closely with graywackes and graywacke-slates. These mica-schists often have the Montalban staurolitic and garnetiferous character. Our own microscopical studies of them have demonstrated their derivation by mere metasomatic changes from rocks wholly of detrital origin,[6] the fragmental character frequently being well preserved, even to the naked eye, while large portions of the same horizon show little change from the original fragmental condition. Thus Hunt places in the Montalban series schists which are most distinctly above rocks which are lithologically Taconian and by him accepted as such. Moreover, he has placed in the same Montalban series certain portions of the schists of Republic Mountain, which belong at the base of the iron-bearing group,[7]

[1] Logan: Geol. Canada, 1863, p. 844.

[2] Geol. Canada, 1863, Atlas. Pl. III.

[3] Proc. Trans. Royal Soc. Canada for 1882–1883, vol. 1, "The Taconic question in geology," p. 250.

[4] Geol. Wisconsin, vol. 3, 1880, p. 659.

[5] Ibid., p. 657: Second Geol. Survey Pennsylvania, E, Trap Dykes and Azoic Rocks, pp. 224–225.

[6] Origin of the mica-schists and black mica-slates of the Penokee-Gogebic iron-bearing series, C. R. Van Hise: Am. Jour. Sci., 3d series, vol. 31, 1886, pp. 453–459.

[7] Geol. Wisconsin, vol. 3, 1880, p. 658.

the granite and associated hornblendic schists of the Menominee region, which, as already indicated, belong to the basement or Laurentian terrane, and even certain granite-like porphyries, which, in the Penokee region of Wisconsin, penetrate in dike form the gabbros at the base of the great Keweenaw or copper-bearing series. Again, the folded slates and cleft slates of the St. Louis River, in Minnesota, have been identified by Dr. Hunt, after an examination of them on the ground, as true Taconian.[1] Had his investigations extended somewhat farther to the south and west he would have realized that these same slates are directly continuous with staurolitic and garnetiferous mica-schists, having all the true Montalban characters.

Next in order above the iron-bearing group in the Lake Superior country comes the great copper-bearing or Keweenaw group, a series of interstratified detrital and eruptive rocks, the latter being in the main of the augitic, basic class, though including also some acidic porphyries. At the base of this great succession, in the Penokee region of Wisconsin, on the south side of Lake Superior, and again occupying an immense area in northeastern Minnesota, is a great development of coarse-grained, augite-plagioclase rocks, which, according to the now most accepted lithological nomenclature, are gabbros. These gabbros include two classes, a non-olivinitic and less basic kind and a highly olivinitic and more basic kind, the olivinitic kinds belonging, in general, stratigraphically below the less basic varieties. These gabbros, which have in the aggregate a most enormous thickness, are beyond question unconformably placed upon the iron-bearing group below, in which latter category I include the Animiké formation of the north side of Lake Superior. In northeastern Minnesota these gabbros, as was first determined by Mr. W. N. Merriam, traverse in a slightly inclined and often even nearly horizontal position the edges of the Animiké formation, which in places they completely overlap, so as to rest directly upon the older granites and schists. The less basic of these gabbros are usually somewhat altered, but, singularly enough, the olivinitic kinds are, setting aside mere surface weathering, as a rule most extraordinarily fresh, rivaling in this respect many modern basaltic flows, with which they have so much in common that their eruptive origin cannot be questioned. As further demonstrative of such an origin, may be cited their entire lithological identity with dike masses found traversing the Animiké series, and also their close lithological similarity to the finer-grained, basic rocks of the higher portions of the Keweenaw series, whose lava-flow origin is certainly beyond question. Were we to classify these widely extended gabbros according to Hunt's order, however, we should be

[1] Proc. Trans. Royal Soc. Canada for 1882–1883, vol. 1, "The Taconic question in geology," p. 250.

compelled to regard them as Norian, in doing which we should not only reject the overwhelming evidence of their eruptive origin, but should be identifying as Norian a formation above the Taconian, that is, at the summit of Hunt's crystalline rock succession, whereas, according to his plan, this formation should belong next to the Laurentian.

There yet remains to be identified in the Lake Superior region the Arvonian of Hunt's classification. There certainly is no such formation in the place to which that classification assigns it, namely, between the Laurentian and the Huronian, but Dr. Hunt himself has recognized as Arvonian various felsitic rocks and porphyries of the Northwest. Thus he has placed at this horizon the felsites and felsitic porphyries of the Keweenaw series of Lake Superior and certain felsitic rocks which are developed at the summit of the quartzite series of central Wisconsin, though he had formerly called both of these Huronian.[1] Of these two sets of porphyries, which belong at quite different horizons, it appears to me that my studies have demonstrated the former—that is, those of the copper-bearing series—to be of eruptive origin, inasmuch as they often occur in dike form and present microscopically all of the characteristics of the modern rhyolites, while the porphyries of the latter horizon present nearly equally strong evidence of such an origin. The former porphyries, then, are later than all of Hunt's groups and the latter succeed sandstones and sandy quartzites which can only be Taconian.

Thus this purely lithological classification of the Pre-Paleozoic groups breaks down completely in its application to the northwestern Pre-Paleozoic. Moreover, not to enter into any general discussion of the crenitic hypothesis (against which hypothesis indeed, as it appears to me, weighty and conclusive arguments might be pressed), it may be said that there is one general consideration which presents itself as an obstacle in any attempt to apply this hypothesis to the Lake Superior region. As set forth in the foregoing quotations, this hypothesis designates all of the Pre-Paleozoic formations (the Keweenaw series being placed within the Paleozoic) as crystalline, separating them into two grand groups of primitive crystalline and transition crystalline rocks. Into the composition of the latter there entered somewhat the products of a subaërial decay of the preceding terranes. In fact, however, the great mass of that group of strata which in the Lake Superior region intervenes between the basement formation and the copper-bearing series is not composed of rocks that are crystalline in the sense of the word as here used. On the contrary, while true crystalline rocks of eruptive origin are included, as also some crystalline rocks of a chemical origin, the great mass of

[1] Second Geol. Survey Pennsylvania, E, Trap Dykes and Azoic Rocks, pp. 229, 232; Proc. Trans. Royal Soc. Canada for 1882–1883, vol. 1, "The Taconic question in geology," p. 233.

this group is composed of detrital materials accumulated most manifestly by the same agencies working in the same manner as in the production of the later formations. These Pre-Paleozoic accumulations, which in the Lake Superior region lie above the gneissic basement formations, were once beds of sand, clay, and pebbles, and, excepting some metasomatic change and some matter introduced interstitially by infiltrating waters, are still made up, in the main, of the unaltered, fragmental materials. The language of the quotations above given is not entirely clear in this respect, but it appears to indicate that all of the rock groups of Hunt's Pre-Paleozoic order are crystalline and were all deposited "anterior to the existence of detrital sediments."

I have felt it necessary to give so much space to a consideration of Hunt's system of classification for the Pre-Paleozoic groups—and incidentally to the crenitic hypothesis—because together they constitute the only logical basis for the use of lithological characters in the determination of these formations in any portion of the world. Outside of the small class of geologists who follow more or less closely the teachings of this system, however, there have been not a few others who have attempted to use lithological characters as a general means of identification of the ancient formations. Thus, Huronian rocks, and even Keweenawan in one case, have repeatedly been recognized in the Appalachians, in the Rocky Mountains, and in the far West, not to speak of other portions of the world. Unless, however, we should accept some such system as the crenitic hypothesis, such identifications, unaccompanied by the very strongest structural evidence, must always rest upon a very flimsy foundation. The great series of highly altered, crystalline, schistose rocks which in the Lake Superior country make with massive rocks the basement formation is probably sufficiently constant in general characters as a whole, or at least in relative amount of alteration and crystallization, to justify us in designating as Laurentian (or as Archæan, should it be decided to restrict that term to this basement formation) any strongly crystalline, schistose series belonging plainly below the fossiliferous formations. Possibly the future may enable us to subdivide the basement rocks into members whose characters may hold over wide areas. As yet no such thing can be done, and lithological evidence can be used in the determination of such a series as that here called Huronian (which owes its existence to processes entirely similar to those by which the later rock groups have been accumulated) only so far as we are dealing with areas that were once manifestly continuous with the type or original Huronian series, and even then this evidence should be relied upon only in proportion to the distance from the type Huronian and should always be taken as subordinate in value to the structural relations of the rocks to be identified. When we proceed to the case of rocks which have been

accumulated in regions of rock growth wholly independent of that in which the original Huronian accumulated, lithological evidence should be allowed no weight whatever.

UNCONFORMITY AS A BASIS FOR CLASSIFICATION.

GENERAL NATURE AND SIGNIFICANCE OF UNCONFORMITIES.

TRUE UNCONFORMITY.

The term unconformity applies to that geological structure which obtains when one group of strata lies upon another in such a manner that the layers of the two groups are not parallel, i. e., the layers of the upper series traverse the edges of the layers of the lower series.

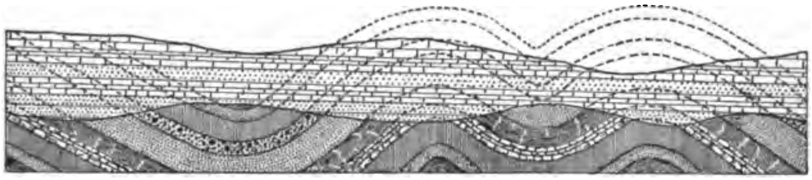


FIG. 64. Ideal section of a true unconformity. Length of section, about five miles. The series of strata represented in the lower half of the figure were, after the deposition of the entire series, bent into mountain folds and raised above the sea, after which the resulting land surface was deeply denuded, and the whole area was then depressed again beneath the sea to receive the undisturbed strata represented in the upper half of the figure.

Such a structure can have been produced in one way only. The lower of the two groups of strata, after having been laid down, must have been disturbed so as to take other than the normal, horizontal position before the higher strata were deposited. The disturbance, except in the unusual case of faultings, must always have been in the nature of a folding. It thus becomes evident that, in order that the layers of the upper series may traverse the edges of those of the lower, there must have been, also subsequent to or contemporaneous with the disturbance of the lower series, a period of erosion during which the crowns of the folds were more or less thoroughly removed. Now, erosion demonstrates the exposure of a land surface to atmospheric action, and consequently, in the case of an unconformity, the elevation of the lower series above the waters of the sea. A genuine unconformity, then—such as is represented in the accompanying Fig. 64, which is ideal, and also in subsequent representations of actual sections—indicates the intervention, between the periods in which the two sets of strata concerned were deposited, of a lapse of time long enough to cover (1) the folding of the lower series, (2) its elevation into a land surface, and (3) a long-continued denudation. In other words, it indicates an interval of more or less extended orographic movement, with its accompanying and following denudation. At times also, particularly when we are dealing with unconformities in

which the oldest known rocks are concerned as the underlying of two series, it becomes evident that the intervening period must have covered also the time necessary to produce a greater or less change in the rocks of the lower series. In any case, however, we have here the indication of a great time gap between the periods in which the two sets of strata were accumulated. Elsewhere this gap may be represented in part, or wholly, by various strata, with their organic remains. Here such a record is wanting. Unconformities doubtless vary greatly as to the lengths of the unrecorded intervals indicated—a point further considered below—but all genuine unconformities, such as we are now considering, must indicate lapses of time so great as to furnish prima facie evidence that the groups of strata which each such unconformity separates must belong to different periods of geological time—evidence which only the weightiest of paleontological arguments, such as the essential identity of strongly characterized and abundant faunas on each side of the gap, should be allowed to overbear.

All unconformities do not necessitate a belief in equally great time gaps. In cases where the lower of the two series is only gently folded and where the amount of material removed in the interval has been relatively small, the time interval necessary for the explanation of the structure is certainly shorter than in those cases where the close folding of the lower series, its high degree of alteration, its great masses of eruptive material, and the relatively plane nature of its extended upper surface demand an intervening period long enough to cover not only great disturbances and alterations, but also the removal of masses of material equivalent in bulk to the greater mountain ranges of to-day. In no case of true unconformity does it appear that the structure can be looked upon as a local phenomenon, demanding only a restricted and local movement for its explanation. Certain authors, indeed, have spoken of unconformities as local in their influence, but, in order that such a statement should be true, the term "local" would have to be taken as indicating, at the very least, areas measured by thousands of square miles, while, in the case of the greater unconformities, it would have to be synonymous with "continental" or even with "intercontinental."

It is true that lack of parallelism more restricted in area between strata of no very great difference in age may be produced in several ways. Thus, the phenomenon of overlap, which is explained below, may give rise to such a lack of parallelism. Even in this case, however, a considerable lapse of time between the periods in which the discordant strata were respectively deposited must be admitted. We might imagine also such a structure as is indicated in the subjoined Fig. 65, which represents a discordance in which the inclined position of the lower strata has been produced by faulting, and not by folding. In this case again, however, a very considerable time interval be-

tween the discordant strata is indicated. Moreover, while we might theoretically conceive of such a structure as of restricted areal extent it is doubtful whether any such structure exists except where the faulting has been an accompaniment of a widespread mountain movement in the interval between the periods represented by the two sets of strata.

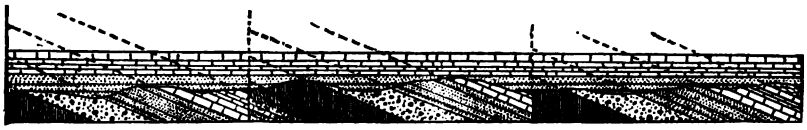


FIG. 65. Theoretical diagram designed to show how a discordance between two sets of strata might arise where the lower strata have been inclined through faulting instead of folding.

In any much faulted or disturbed region strata of the same age or of but little difference in age may present themselves in steeply inclined and in horizontal attitudes at places in close proximity to one another. Such structures might at times erroneously suggest the existence of a true unconformity; but with a genuine unconformity they have, of course, nothing whatever in common.

THE EROSION INTERVAL.

Interruptions in the continuity of stratal deposition may be indicated which do not argue genuine unconformities. It is of course possible, theoretically, that a region of the sea bottom may, after a series of strata has formed upon it, receive no further detritus for a considerable period, after which further supplies of land detritus or of organic secretions may come in to continue the growth of the conformable pile. In such a case there would be nothing beyond a possible strong contrast in the rock materials or in fossil remains to indicate the intervention of a period of non-deposition. It is hardly conceivable to me, however, that such periods of non-deposition could be very long continued, unless the area should be raised above the level of the sea. Our stratified rocks, in the main, have been spread over the surface of a submerged continent, and it seems hardly probable that the supply of material should have been withheld if the area remained submerged for a very long period of time. Being raised above the sea a given area may, of course, remain through an indefinite length of time without receiving new material. Inasmuch as this raising above the sea may be produced without folding of the strata, it follows that upon further submergence new material may be deposited over the old in an essentially conformable manner. In such cases, however, the indications of the former existence of a land surface and of the intervention of a period of erosion will often be met with in the midst of the finished pile of strata. The structures which result are often spoken of as unconformities by

erosion. The phrase is an unfortunate one, however, since the word unconformity distinctly implies a lack of parallelism between the strata on opposite sides of the break, and moreover all true unconformities indicate folding as well as an intervening erosion.

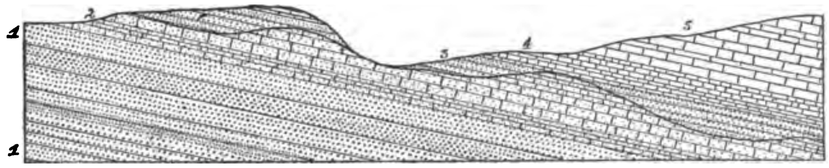


FIG. 66. Section illustrating the eroded upper surface of the Lower Magnesian limestone, eastern Wisconsin; 1, Potsdam sandstone; 2, Lower Magnesian limestone; 3, St. Peter's sandstone; 4, Trenton limestone; 5, Galena limestone.

Eroded surfaces among conformable strata may correspond to time gaps of fully as great length as those represented by many true unconformities. On the other hand, it is evident that they may also correspond to intervals of relatively insignificant length. In Fig. 66 we have illustrated an eroded surface among conformable strata corresponding to a relatively short interval of time. The section represents the conditions which obtain through a large part of southern and eastern Wisconsin. The pile of strata is as follows: At the base is the Potsdam sandstone, which grades upward into the Lower Magnesian limestone. By their fossils and by their gradations into one another we are justified in referring both of these formations to the Cambrian series. The upper surface of the Lower Magnesian is an irregular one, the irregularities being in part a result of erosion by atmospheric agencies. Upon this irregular surface of limestone now follows the St. Peter's sandstone, an extraordinarily widespread layer of quartzose sandstone, which ranges in thickness from over two hundred feet to less than one foot, at times even disappearing altogether, the overlying and underlying layers coming in contact. These variations in thickness are often very abrupt, revealing to us the existence on the upper surface of the Lower Magnesian of erosion irregularities over a hundred feet in vertical height. Succeeding the St. Peter's sandstone, without other indication of unrecorded lapses of time, we find a great succession of Lower and Upper Silurian strata. The time gap indicated by this structure as having intervened between the respective periods of deposition of the Lower Magnesian and St. Peter's formations must have been sufficiently long to cover an elevation of the limestone above the level of the sea and its erosion, at least to the extent indicated by the irregularities of its upper surface. But manifestly such a gap bears no comparison to what is required for the least of the genuine unconformities.

The upper portion of the Lower Magnesian limestone illustrates also an interruption in stratal deposition corresponding to a yet

smaller lapse of time (Fig. 67). Professor Chamberlin has shown in his discussions of Wisconsin geology that the irregularities of the upper surface of the Lower Magnesian limestone are only in part due

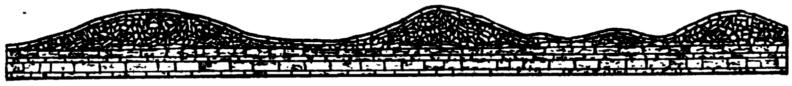


FIG. 67. Section of the upper surface of the Lower Magnesian limestone, Wisconsin.

to an erosion entirely subsequent to the deposition of that formation, having been, in some measure, produced by an erosion within the period of deposition of the Lower Magnesian itself. Many of the protuberances on the upper surface of that formation have a most singular brecciated structure internally, such as seems to indicate the breaking action of the waves of the sea. Forming the outer side of the protuberance, however, and lying upon and completely cloaking the brecciated interior, is a continuous layer of limestone which seems to represent the fine silt which was deposited upon the surface of the brecciated material at a time of subsequent but slight submergence of the surface of the formation. The emergence and submergence of the upper surface of the Lower Magnesian thus indicated plainly correspond to a relatively short lapse of time and seem to have been merely preliminary to the general emergence which produced the irregular surface upon which the St. Peter's sandstone was deposited.

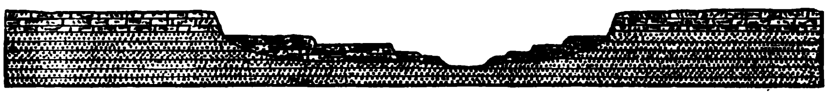


FIG. 68. Section of a river valley in the region of the Upper Mississippi.

Fig. 68 shows a form of interruption among conformable strata which presents itself to us constantly and which represents a time gap of immense duration, one which is at the other extreme from the gaps indicated by Figs. 66 and 67. In Fig. 68 we have a series of horizontal strata belonging, say, to the Cambrian period, as for instance from the Upper Mississippi Valley. Filling the bottom of a valley eroded from this formation is a river silt of the present time.

OVERLAP.

Standing between the true unconformity and the simple erosion break as to length of time-gap necessarily indicated is the structure known as overlap. This structure is explained in the ordinary text-books of geology and is illustrated in Fig. 69. The left-hand end of the figure, which must be taken as many miles in width, represents above the folded layers an essentially conformable series of strata. As the section is followed to the right the middle members of the

series thin out and disappear, the uppermost and lowermost members spreading, however, to the extreme right of the section, where they come together in a slightly discordant attitude. Such a structure as this is explicable in this way: All except the uppermost member of the series were deposited in an area gradually undergoing depression on the left and elevation on the right. As this elevation progressed the right-hand end of the section represented was elevated above the sea more and more and the middle members of the series became consequently more and more limited as to extent in that direc-

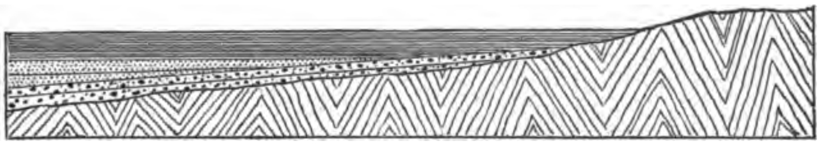


FIG. 69. Overlap.

tion. Finally, the depression affected the whole of the region represented and the uppermost member of the series spread over the whole area. Such a structure as this, particularly if there be any considerable discordance between the upper and lower layers of the series, could only obtain when the intervening members were of very considerable thickness, and corresponded, therefore, to a very considerable lapse of time.

DISTINGUISHING CHARACTERS OF TRUE UNCONFORMITIES, WITH EXAMPLES.

CASES IN WHICH THE OVERLYING STRATA ARE UNDISTURBED.

Visible superpositions.—Unconformities are structures measured by scores and hundreds of miles, for which reason, and also because the formations below the unconformities have been more or less deeply buried underneath later accumulations, it follows that anything like a single comprehensive view of an unconformity is to be obtained only under very unusual circumstances. Such circumstances are met with, for instance, in the depths of the Grand Cañon of the Colorado, where, all cloaking by superficial detrital material or vegetation being wanting, a pile of strata many thousand feet in thickness and ranging from the Potsdam horizon upward may be seen traversing for miles the upturned edges of the great formation to which Powell has assigned the name of the Grand Cañon group. More commonly we are able to see actual superpositions or horizontal layers upon upturned strata through limited distances only. Such occurrences obtain where general denudation has carried the present surface, in the main, below the level of the ancient land surface beneath the unconformity, leaving the horizontal strata as cappings to the summits or as facings to the sides of elevations composed of the lower rocks. By putting together a series of such occurrences in

the same region we are enabled to work out the general character of the unconformity, though at best it will usually be but a very small portion of its whole extent that we are thus able to investigate. This is illustrated, for instance, in Fig. 70. Here the erosion which has produced the present surface intersects the unconformity in the vicinity of what was the limit of the sea in which the horizontal formations were accumulated.

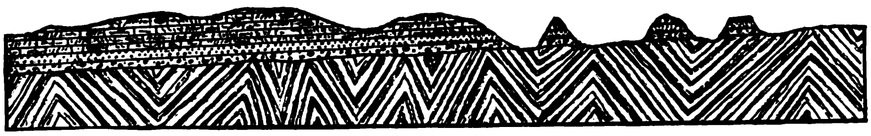


FIG. 70. Diagram showing how an extended unconformity may be rendered visible by denudation only in the immediate neighborhood of the line of junction of the surface areas of two discordant sets of strata, e. g., in central Wisconsin. To the right the lower formation is at the surface for many thousands of square miles; to the left, however, it is everywhere covered by the undisturb d strata.

Lateral contacts.—A not uncommon case is that where the surface of the formation below the unconformity makes a more or less sudden rise in elevation, later denudation, in such cases, having removed the horizontal layers from the higher portion of the old land surface and having left them over its lower portion. Such an occur-

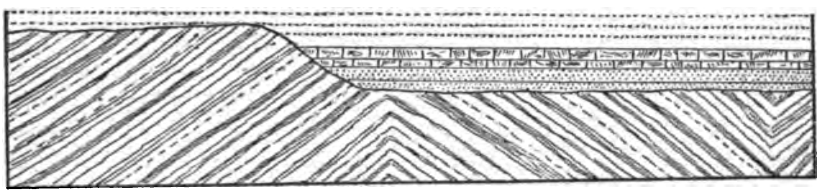


FIG. 71. Diagram illustrating an unconformity where the upper formation has been denuded from the higher portion of the ancient land surface and left upon its lower portion, the result being that the only visible contact of the two is a lateral one.

rence is illustrated in Fig. 71, and it is manifest that in such cases, unless we are favored by deeply cut natural ravines crossing the contact, we may have only an abutment of the horizontal layers laterally against the tilted ones upon which to base our conclusion as to unconformity. Between such cases as that illustrated in the figure and those where more or less extended actual superpositions are visible, all degrees of variation are to be found. In such extreme but yet not so very unusual cases as that represented in the figure we must of course guard against the danger of mistaking a fault for a genuine unconformity. Various phenomena liable to occur at the contact will serve to aid us in avoiding this mistake, and particularly the occurrence in the overlying formation of more or less abundant fragments from the lower rocks. Cases are at times met with—as, for instance, those cited below as occurring at the contact of the Keweenaw series of Lake Superior and the horizontal Pots-

dam sandstone on Keweenaw Point and elsewhere—where the unconformable abutment has been against an ancient fault cliff. At some period subsequent to the laying down of the newer series a second, but relatively slight, faulting has taken place along the old fault line, in which case a singular disturbance of the edge of the overlying formation has resulted, giving rise to confusing and contradictory appearances (Fig. 72).

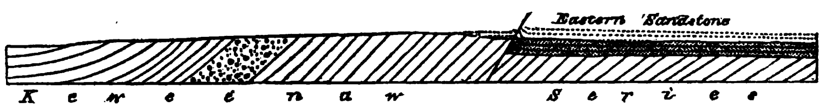


FIG. 72. Case of unconformity where erosion has removed the horizontal layers from the higher portion of the ancient land surface, leaving only a lateral contact visible, along which faulting has produced confusing appearances. Keweenaw Point, Mich., and Douglas County, Wis.

Basal conglomerates.—As an eroded land surface slowly sinks beneath the sea, the waves, beating on its more prominent projections and irregularities, break them down and from their ruins form new deposits. The coarse part of the material thus derived—such as the greater masses that fall from overhanging sea-cliffs, or the bowlder heaps which form at the base of such cliffs, or the shingle which collects in recesses between projecting rocky points—will remain at no considerable distance from its source, while the finer materials will be carried to distances great in direct proportion to their degrees of fineness and to the strengths of the currents acting upon them. These finer materials will thus be spread over the intervening relatively low and level portions of the ancient land surface, which portions will have been in large measure protected from the action of the waves by the silt and stream detritus which have been washed into them during the exposure of the region to the action of the subaërial agencies. The distribution of the wave-made débris is thus irregular in proportion to its coarseness, and the irregularity will be of two kinds, for not only will the distribution laterally (i. e., over the ancient land surface) be irregular, but there will be also the greatest irregularities as to the vertical distribution (i. e., the distribution in horizon) among the deposits beneath which the land surface is gradually buried. The latter irregularity will arise from the variations that will obtain as to vertical height and abruptness and nature of rock material among the projections which furnished the fragments.

The coarser fragmental materials consolidate into what are known among geologists as conglomerates, or as basal conglomerates when they lie, as they frequently do, at the contact of two discordant formations (Fig. 73). In every respect, as to position, distribution, etc., these basal conglomerates reproduce the conditions we now see obtaining along exposed and rocky lines of coast. Their occurrence is not only a characteristic feature of unconformable contact lines, but

often serves to establish the existence of unconformities when other evidence may be wanting by reason of various obscuring causes. It is true that coarse, wave-fashioned, fragmental materials may be embraced in a rock which is not geologically remote from that which furnished the fragments, as in the case of certain lavas which, flowing directly into the sea or becoming submerged beneath the sea by depression at a period not long subsequent to their eruption, may yield fragments as soon as acted upon by the waves. Similarly such limestone masses as are formed near to the surface of the sea—for instance, certain of the coral-derived masses of to-day—yield fragments to deposits of the same geological age; and it is at least conceivable that the same might be the case with certain forms of chemical sediments which have reached the indurated condition at an early period in their history. But such occurrences as these give little trouble to the experienced geologist, who knows that, with the exception of the cases cited, the inclusion of the fragments of one rock within the mass of another indicates a period of time between the formation of the two sufficient to cover the raising of the lower one from its original position beneath the sea and its induration and transformation into its present condition.

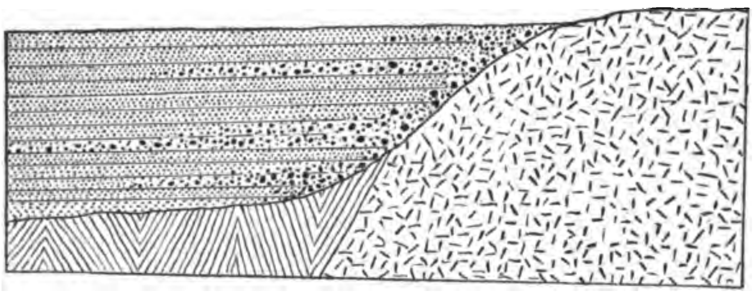


FIG. 78. Diagram designed to show the necessary irregularity in the stratigraphical distribution of a basal conglomerate at the junction of two discordant formations.

The existence of such conglomeratic masses may indeed form the main evidence upon which conclusions as to unconformity are based. We may suppose, for instance, a case of what is above called lateral contact, where the horizontal formation, underlying a level and relatively low region, comes against the edges of a series of tilted strata forming a more elevated region. Such a break is conceivably resultant from a process of faulting, in which case the discordance in attitude of the two formations at the contact may give place to entire concordance beneath the horizontal formations of the lower area. But if the horizontally placed terrane be crowded with fragments of the tilted one at and near the contact of the two, it becomes evident at once that the tilted strata acquired their disturbed position prior to the deposition of those that lie horizontally against them.

Relation of eruptives to unconformable contacts.—The erosion which the upper surface of the formation below the unconformity has suffered will frequently have truncated the eruptive masses which have penetrated that series prior to the erosion; whereas those eruptives which have been intruded at a time subsequent to the deposition of the overlying series will intersect the contact line. A consideration of this simple principle will frequently aid in the establishment of an unconformity where otherwise its existence might not be so evident. This will particularly be the case when the overlying strata are more or less disturbed, as noted below.

The general relative attitudes of unconformable formations.—Cases of very considerable unconformity occur where neither direct superposition nor lateral contacts may be obtained to establish the relation. Even in these cases, however, the unconformity may often safely be inferred from the general relative attitudes of the two formations. Suppose, for instance, a case where an extended level area, underlaid by horizontally placed strata, may terminate against an elevated one composed of more or less folded and crumpled formations. While the actual contact of the two terranes may be concealed it may yet be sufficiently evident from the horizontality of the one and from the greatly disturbed and perhaps altered condition of the other that there is here a genuine unconformable break. Particularly will this be plain if the horizontal strata of the newer enter into the sinuosities of the edge of the area occupied by the older terrane. Nevertheless great caution needs to be taken in such cases as this, since such relations between horizontal and disturbed strata as are here supposed might at least conceivably obtain where the disturbed strata pass in an undisturbed condition, and conformably, beneath the horizontal strata of the lower area. But in those cases where the older formation is very much folded and is greatly different in character from the horizontal one, and particularly if its rocks are greatly altered, the presumption is that we have to do with an unconformity.

EXAMPLES.

Pre-Potsdam land surface of central Wisconsin.—The distribution and lithological character of the basal member of the Paleozoic column of the Mississippi Valley—now well established as the equivalent of the Potsdam sandstone of New York—and its relations to the formations upon which it reposes render it evident that it was deposited in a sea advancing from the south and gradually encroaching on the great land mass which lies to the northward, as has been fully shown by Chamberlin.[1] This encroachment continued until that portion of this ancient land mass which now presents itself at the surface in northern Wisconsin and northwestern Michigan was entirely surrounded and detached from the main mass over the

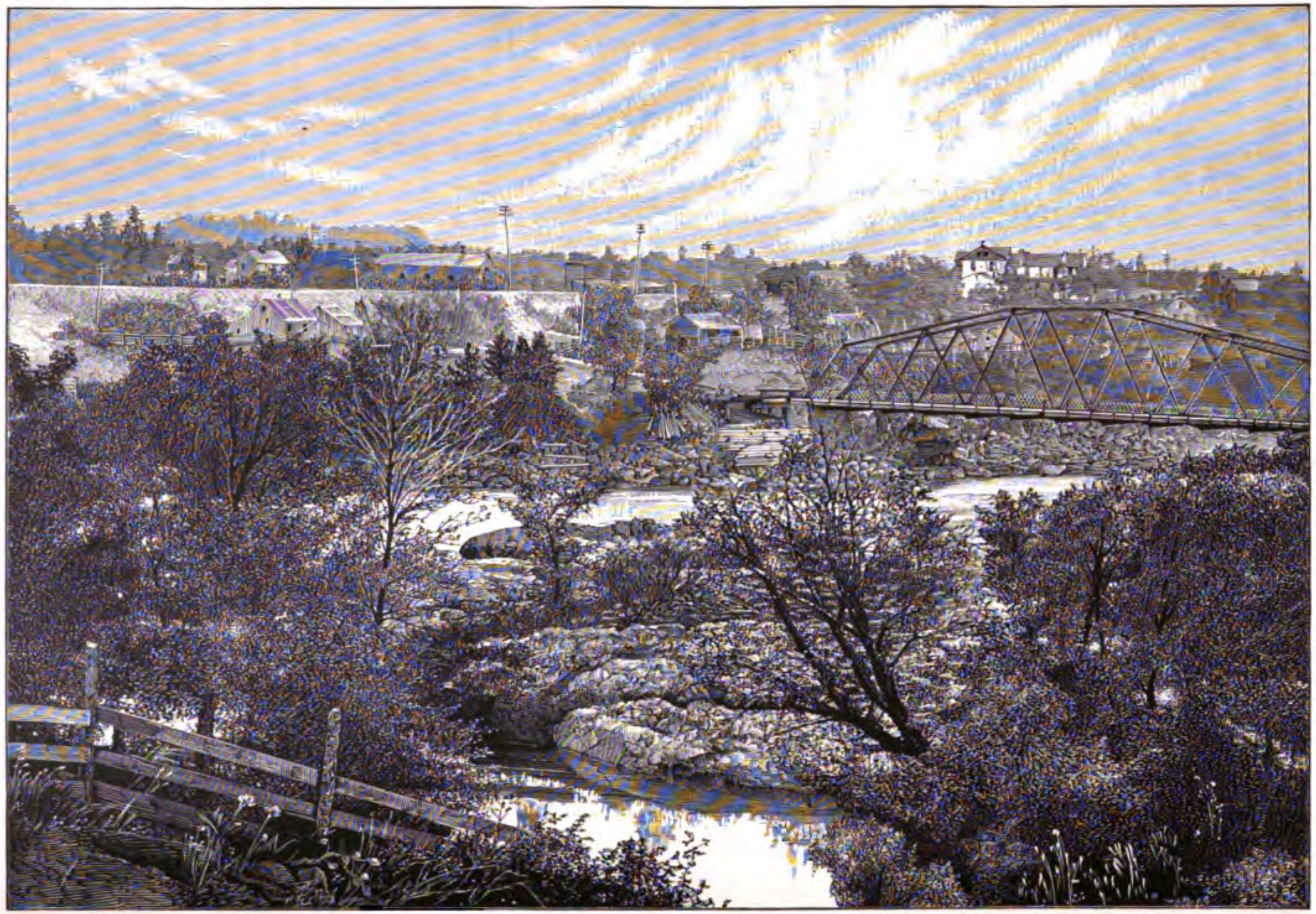
[1] Geol. Wisconsin, vol. 1, 1883, pp. 119-137.

great Archæan region of Canada. A geological map of the region extending southward from Lake Superior as far as southern Wisconsin, such as that compiled by myself and published in the Fifth Annual Report of the U. S. Geological Survey, will indicate roughly how far this encroachment of the sea extended. In fact, however, the encroachment was in places somewhat greater than such a map indicates, for the sandstone has since been partly removed by the denuding agencies and the area in which the older formations are at the surface is somewhat extended. It has also resulted from this denudation that the line between the two formations is an exceedingly intricate one. High, isolated patches of the sandstone have been left within the area occupied by the older formations, while the valleys of the deeper streams within the sandstone area proper have often cut their channels for long distances down to the ancient land surface upon which the sandstone formation reposes. Everywhere within the vicinity of this boundary, except where the drift covering is too great, are to be found sections most instructive in their bearing upon the relations of the sandstone to the older formations.

Nowhere are these more instructive than in that central portion of the State of Wisconsin whose geology is indicated in the accompanying map and sections. This region, moreover, is of especial interest in the present connection because, in addition to the contacts in the immediate vicinity of the common boundary of the main surface areas of the two formations, it shows others at a number of points, where there rise within the sandstone area projecting portions of the underlying basement, which owe their elevation to their greater relative power of resistance to the denuding agencies. The structure of this district has been worked out very completely by the Wisconsin survey, from the maps of which survey the map herewith presented is mainly reproduced. The original work for the larger part of this area was my own, but the map includes also considerable portions of the districts on the east and west, in which the original field-work was respectively by Prof. T. C. Chamberlin and Mr. Moses Strong.

From the large surface exposure of the Pre-Potsdam formations in the northern part of the area mapped and north of it, from the numerous smaller areas which come to the surface within the region of the horizontal formation, and from the records of numerous borings for artesian flows, we are enabled to reconstruct in the most satisfactory manner the nature of the ancient land surface upon which these horizontal formations repose. We are even able to reach a satisfactory approximation to the distribution of the different formations which compose the ancient basement where concealed by the horizontal accumulations.

This ancient surface is one made up of that class of rocks to which the name of crystalline schists has been applied. Gneiss, various mica-schists, hornblende-schists, chlorite-schists, and granites make



VIEW IN THE BLACK RIVER VALLEY, BLACK RIVER FALLS, WISCONSIN.

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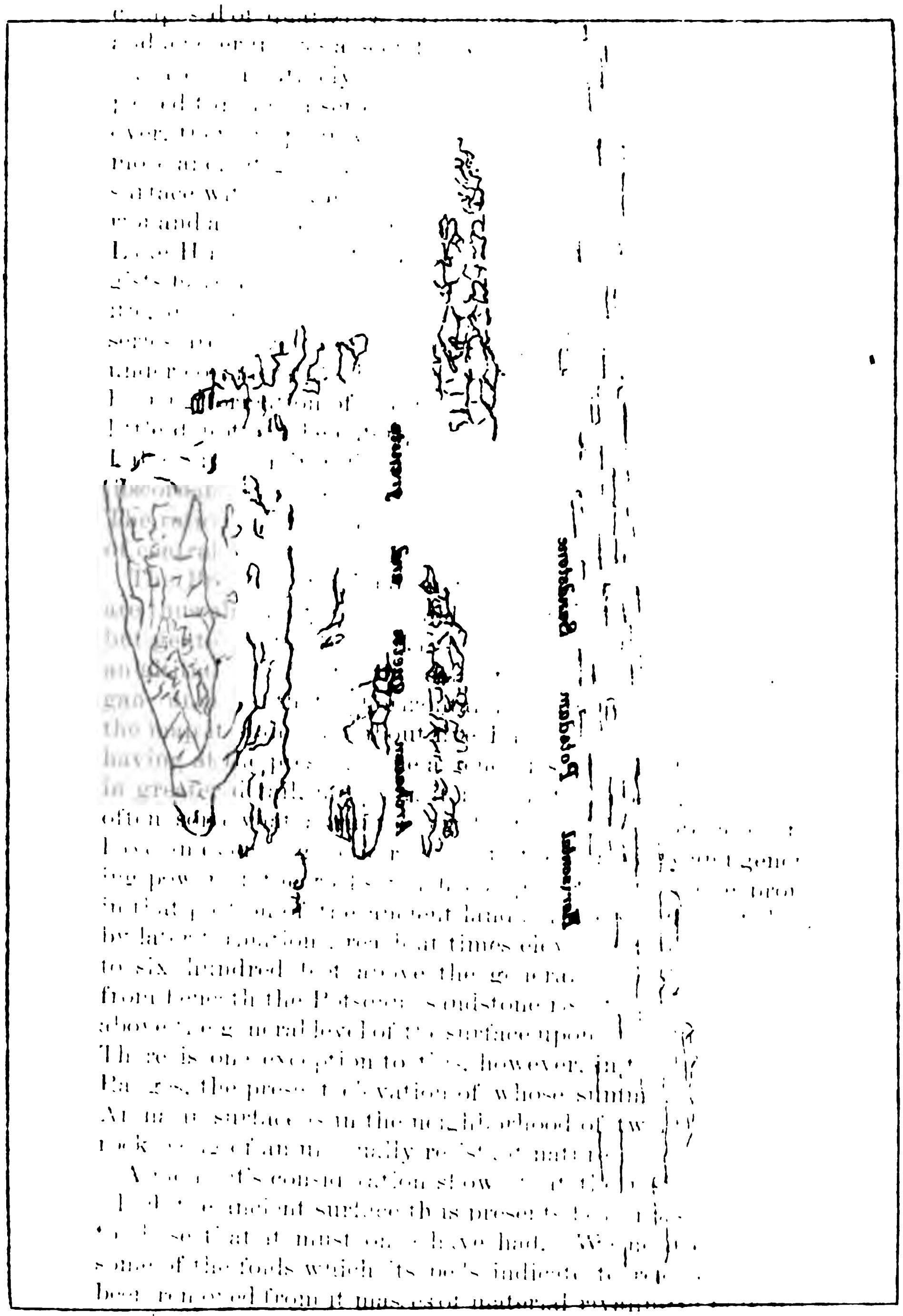

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VIEW IN THE BLACK RIVER VALLEY, BLACK RIVER FALLS, WISCONSIN.

up the larger part of the basement. Another large part is chiefly composed of quartzites, ferruginous schists, and certain other schists and acid eruptives associated with them. Basic eruptives also occur, but are of relatively limited distribution. All of these rocks have passed through a series of profound foldings and alterations. Moreover, they are plainly divisible into two dissimilar formations: (1) a more ancient gneissic formation, which is actually continuous at the surface with the gneissic formation of the south shore of Lake Superior and almost as certainly with the great gneissic formation north of Lake Huron and east of Lake Superior, to which the Canadian geologists have applied the term Laurentian, and (2) a more recent quartzitic, iron-bearing series, whose structural relations to the gneissic series are, to be sure, not apparent within the district particularly under consideration, but whose community of nature with the iron-bearing formation of the Lake Superior country is so striking that little doubt can be entertained of the equivalency of the two. The Lake Superior iron-bearing rocks can be most plainly shown to be discordant with the gneissic formation with which we are concerned. The rational inference is that the quartzitic, iron-bearing formation of central Wisconsin holds the same structural relation.

The Pre-Potsdam land surface, whose structure and position we are thus able partly to see and partly to infer, is one, in the main, of but gentle undulation. In the vicinity of Lake Superior it reaches an altitude of about a thousand feet above the level of Lake Michigan; underneath the horizontal formations of the southern part of the map it stands at about five hundred feet below the same level, having at the present time a general southerly descent. Looked at in greater detail, however, it is seen to have numerous minor and often somewhat abrupt irregularities. The more abrupt of these have an evident genetic relation to the durability and general resisting power of the rocks which compose them. These prominences, in that portion of the ancient land surface which is still uncovered by later formations, reach at times elevations of from one hundred to six hundred feet above the general surface. Those that rise from beneath the Potsdam sandstone rise to about the same extent above the general level of the surface upon which that formation lies. There is one exception to this, however, in the case of the Baraboo Ranges, the present elevation of whose summits above the general Archæan surface is in the neighborhood of twelve hundred feet, the rock being of an unusually resistant nature.

A moment's consideration shows that the insignificant elevations which the ancient surface thus presents bear no sort of comparison to those that it must once have had. We need only to trace out some of the folds which its beds indicate to realize that there have been removed from it masses of material rivaling in bulk the greater existing mountains of the globe, and this is as true of the layers be-

longing to the later as of those belonging to the older one of the two formations concerned. What remain now are the mere stumps of mountains. Our views may vary as to the exact chronological relations of the periods of folding of these strata and of the decapitation of the folds. These two processes may or may not have been more or less contemporaneous; but whether contemporaneous or not, it is evident that an amount of material vast beyond computation was removed from this ancient land before the encroachment upon it of the sea within which the sandstone was deposited. The only measure of this material that we now possess is that afforded by the stratified accumulations of all later geological time.

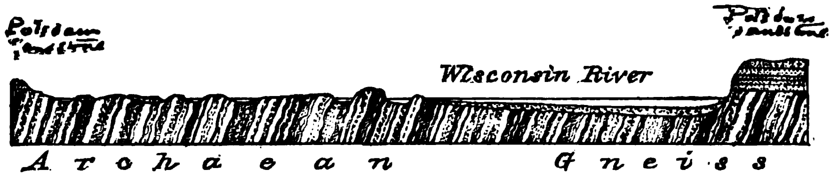
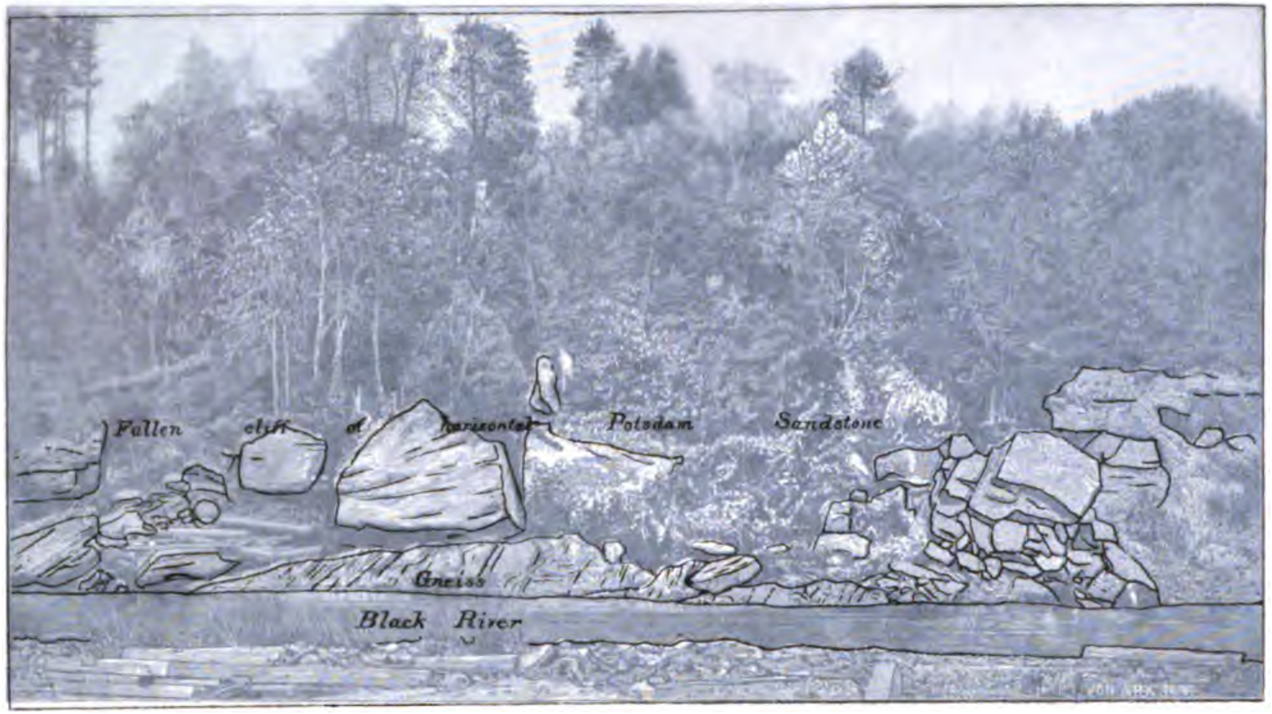


FIG. 74. Section across the valley of the Wisconsin River near Point Bass, Wood County, Wis., looking north. The Potsdam sandstone, which forms the surface rock everywhere on each side of the stream, is here cut through so as to show its unconformity to the underlying gneiss. Scale, 225 feet to the inch.

Contacts with the gneissic or older one of the two formations of which this Pre-Potsdam land surface is composed may be particularly well seen along the valleys of the several streams which intersect the northern edge of the sandstone area, and especially the Wisconsin and Black Rivers, with their several branches (Fig. 74). As will be seen from the map, the immediate valleys of these streams uncover narrow strips of the ancient gneisses a number of miles in length. At times these strips are no wider than the river bed itself; in other cases they extend some little distance to either side of the stream. The gneisses and associated schists stand always at very high angles and present a nearly level, truncated upper surface which is at times free from loose material and is again in places changed to a kaolinic substance. Resting horizontally upon this surface, in the valley sides or even in the immediate banks of the rivers, is seen the Potsdam sandstone. Exact contacts of the two formations are frequently to be found. When the tops of the valley sides are reached we find ourselves upon a generally level surface, everywhere underlaid by the sandstone formation, bold castellated remnants of which here and there dot the plain. The sections of the Black and Wisconsin Valleys here given, as also the views in the vicinity of Black River Falls (Pl. XXX), will serve to make this relation plain (Fig. 75). It is very evident that we are dealing in these places with the greatest kind of a geological break. Between the periods which gave rise, respectively, to the gneissic and the sandstone formations (Pl. XXXI) intervened a lapse of time sufficient to cover the alter-



UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND ARCHÆAN GNEISS.

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UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND ARCHÆAN GNEISS.

UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND FERRUGINOUS SCHISTS.

ation of the gneisses from their original condition (whatever that may have been), their elevation into mountain masses, and the complete removal of such masses, this thorough truncation being indicated not only by the present folded condition of the strata, but also by the appearance at the surface of areas of eruptive granite and other coarsely crystalline rocks which we can only suppose, with our present knowledge, to have formed deep within the interior of the earth.

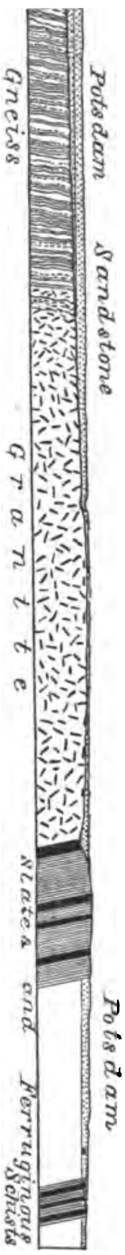


FIG. 75. Section on Black River in the vicinity of Black River Falls, Wis., showing the Potsdam sandstone resting on an eroded surface composed of granite and steeply inclined layers of gneiss and of ferruginous schist. Scale natural, 2 miles to the inch.

When we come to consider the relations between the sandstone and the newer of the two formations composing the old land surface, we find that here again there seems to be required an enormous interval of time (Pl. XXXII). It cannot, of course, if our reading of the geology of this region be correct, have been anything like so long as in the case of the unconformity between the Potsdam sandstone and the older of the basement formations; but it must have been long enough to cover the folding, induration, and removal of mountainous masses of material. These relations are illustrated partly in a section already given, viz, that along the valley of the Black River, in which the sandstone is seen to cross indifferently the gneisses of the older formation and the folded ferruginous schists of the newer. But the most interesting and striking occurrences to be mentioned in this connection are those met with in the Baraboo region farther south. An inspection of the map herewith will show that in this region there rises to the surface a large area of the newer of the basement formations, and that, stretching out thence in a direction northeastward for a distance of some fifty miles, numbers of other smaller points of this formation reach the present surface; while at a distance of some thirty miles in a southeasterly direction another group of small areas presents itself. In the Baraboo region most of the rock at surface is a quartzite of some form, but in the more northern portion of the area ferruginous and cherty schists and felsitic porphyries occur with a very considerable development, and similar porphyries make up several of the isolated areas which lie to the northeast. Borings of numerous artesian wells farther to the northeast and east indicate a very considerable distribution in that direction of a similar material beneath the horizontal formations.

In the immediate vicinity of all these areas the outcroppings of the horizontal formations are found, and not unfrequently direct

contacts, in which latter case, if the horizontal formation be a sandstone, either the St. Peter's or the Potsdam, it is found filled with fragments or masses of the older rock. But the most striking sections are those to be found about the Baraboo Ranges. In this region the quartzite formation comes to the surface in the shape of two bold ridges, which unite at their eastern and western extremities, forming together the great mass of high land which causes the great eastern deflection in the present course of the Wisconsin River. I say present course, because it is manifest that at a former period this river had its course across the two ranges, passing through gorges which still remain, though one of them is now badly blocked with morainic drift. Between these two ranges lies a valley, into the western end of which the Baraboo River breaks from the north through a narrow gorge. Traversing then a great part of the length of the valley, this river leaves it again to the north, passing out at the gorge formerly used by the Wisconsin River. All around the outer circuit of the ranges the country is occupied by the Potsdam sandstone, which rises frequently high on their flanks and, although never reaching their uppermost swells, which lie at elevations of over seven hundred feet above the adjacent valley of the Wisconsin River, often overtops the lower elevations, particularly in the case of the northern range. The same sandstone has evidently at one time filled completely the intervening valley. This is evident from the way in which it now lies on the flanks of the inner sides of the ranges and from the fact that it still fills to the brim the eastern end of this valley. Often the sandstone remnants on the sides of the ranges are found filling depressions in the ancient surface or forming mere facings to the sides of ravines, in which cases, many in number, it is manifest that the new erosion has followed the course of the erosion of that remote period when the outlines of the ancient land surface were carved.

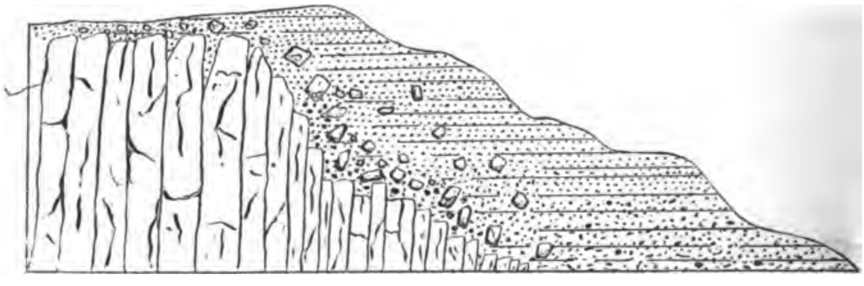
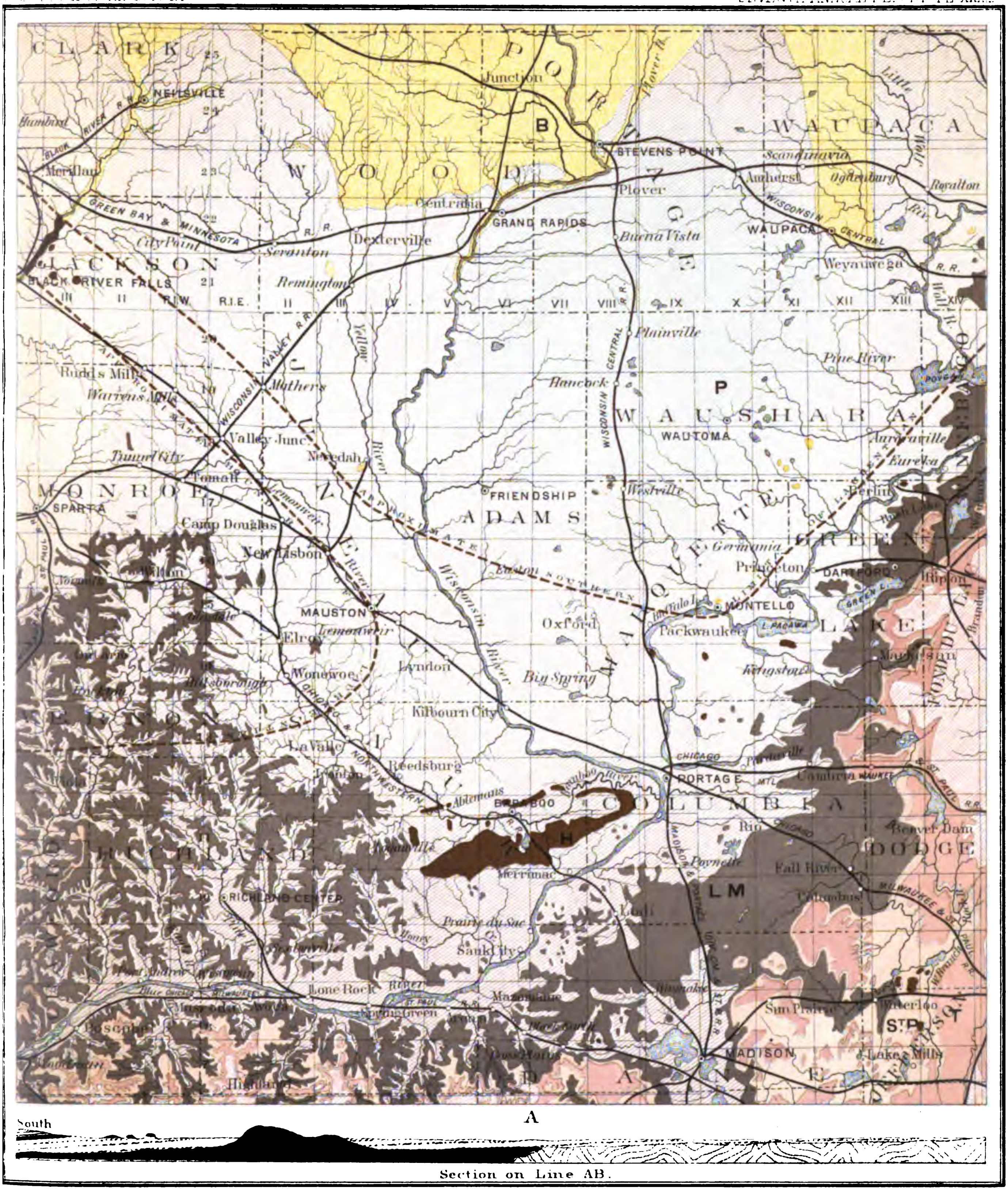


FIG. 76. Contact of Huronian quartzite and Potsdam sandstone. South end of the cliff on the east side of the upper narrows of the Baraboo River, near Ablemans, Wis. Scale, 50 feet to the inch.

As one approaches these ranges from various directions fragments of the rocks composing them begin to occur within the newer formations, and this not only in the Potsdam sandstone, but in the Lower



LOWER SILURIAN: Galena Limestone G; Trenton Limestone T; St. Peter's Sandstone St P
CAMBRIAN: Lower Magnesian Limestone; Potsdam Sandstone P
HURONIAN
LAURENTIAN: Gneissic Series

Scale 1 inch = 15 miles

Vertical Scale 1 inch = 8,000 feet.

GEOLOGICAL MAP OF CENTRAL WISCONSIN.

Designed to indicate the character of the ante-Potsdam land surface.

Based on Maps of the Geological Survey of Wisconsin, by T.C. Chamberlin, M. Strong and R.D. Irving.

Magnesian limestone above it. These fragments, very small to be sure, but of quite unmistakable derivation, have been met with as much as ten or fifteen miles to the south of the southern range. Nearer the ranges they occur more frequently, until at the actual contacts between the sandstone and the quartzite genuine bowlder conglomerates are met with. At times these contact conglomerates are not very coarse, being composed of much-rolled fragments. In

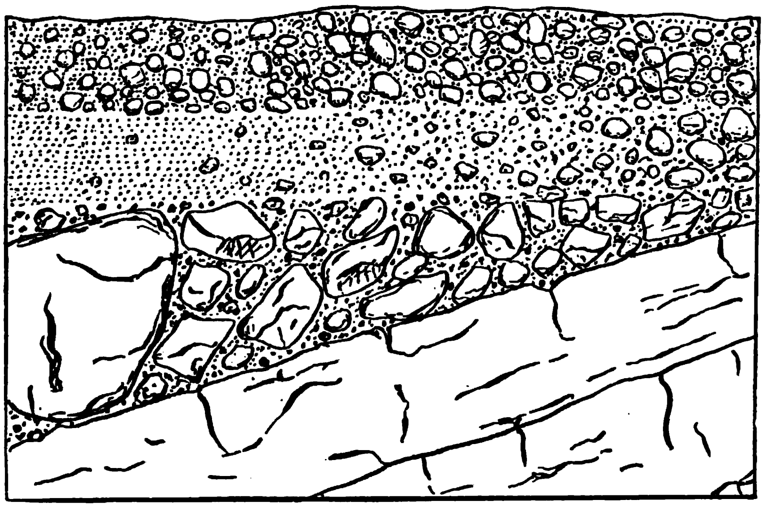


FIG. 77. Basal bowlder conglomerate of Potsdam sandstone lying upon gently dipping layers of Huronian quartzite, Devil's Lake, Wisconsin.

other cases, however, where the conditions have been favorable the sandstone has included within it great masses of the quartzite many feet in length and breadth. These occur principally where the quartzite has formed a nearly vertical or overhanging cliff in the sea within which the sand was deposited (Pl. XXXIV and Fig. 76). In other cases the waves of the sea, washing up the slopes of the not very steep dip surfaces of the ancient reefs, have formed accumulations of bowlders of considerable size, which generally present some tendency to rounding at the corners (Fig. 77).

FIG. 78. North and south section through the Baraboo Ranges, looking east. The section shows the horizontal Potsdam sandstone, with a remnant of the Lower Magnesian limestone above it as a capping to a single bluff, lying upon the deeply denuded surface of the Huronian quartzite and quartz-porphyry.

The points at which contacts between the two formations are to be found, and at which the most striking and interesting conglomerates are to be seen, are far too many to notice in this connection. I may merely give two or three sections, along with reproductions

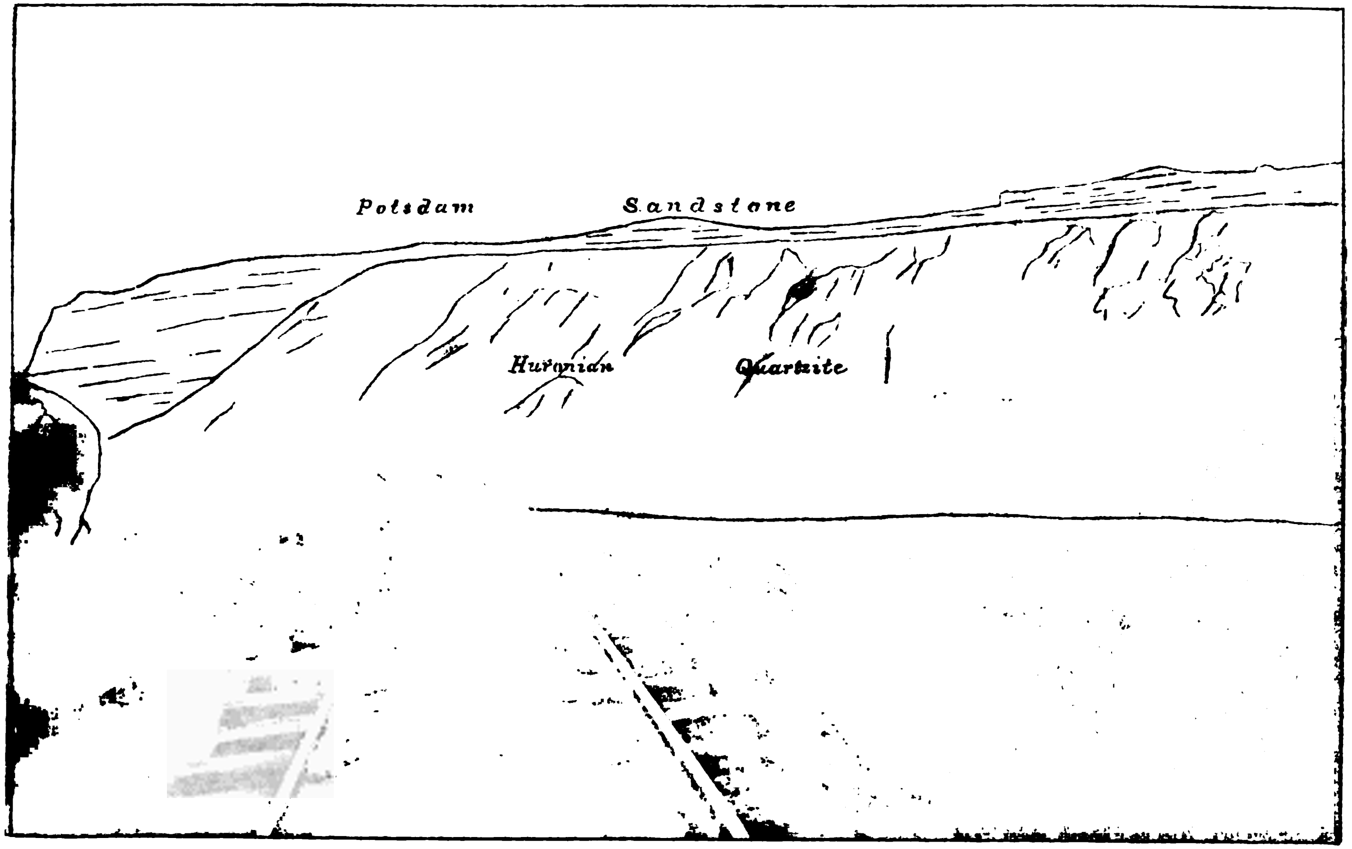
of some photographs recently taken, in order to set the occurrences more plainly before the reader (Pl. XXXV). The section shown in Fig. 78 extends from some miles south of the more southerly of the two ranges, crossing both ranges and their intervening valley, and some little distance also to the north of the northern range. It is designed to show the general relation of the ancient formation to the sandstone. Fig. 79 is a section showing on a true scale the occurrences met with on the west side of the gorge through which the Baraboo River crosses the northern range to the north.

FIG. 79. North and south section through the northern one of the Baraboo Ranges at the lower narrows of the Baraboo. Scale natural, 4½ inches to the mile. The Potsdam sandstone overlies the quartzite unconformably and is filled with fragments from it.

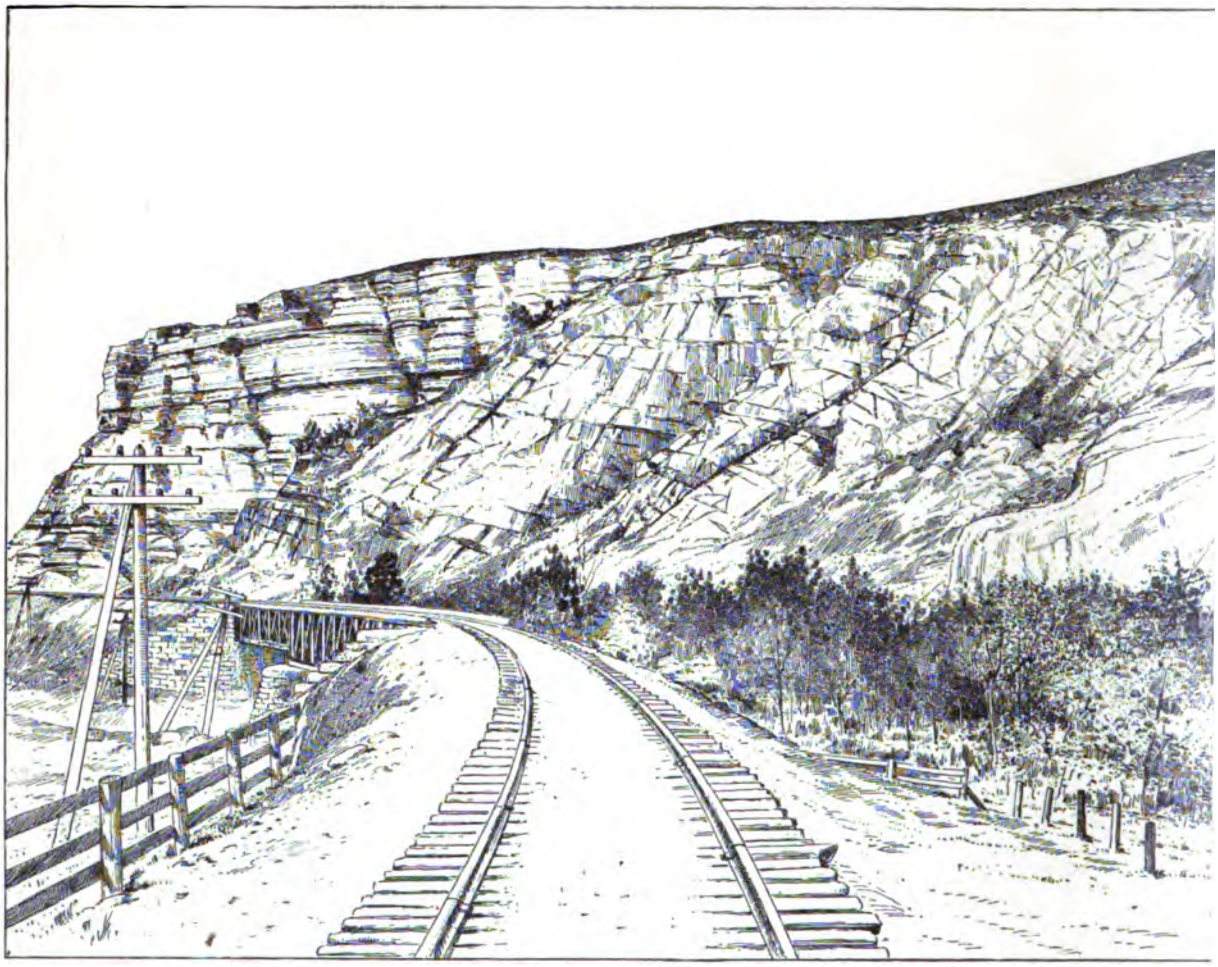
Fig. 77 and Pls. XXXVI and XXXVII are illustrations of the occurrences in the immediate vicinity of Devil's Lake, a picturesque sheet of water occupying a depression between the great heaps of drift which now block the gorge in the southern range formerly used by the Wisconsin River. Pl. XXXVII, on which is represented a mass of bowlder conglomerate overlying quartzite, is of especial interest because it illustrates the way in which the conglomerate in this vicinity lies upon the gently sloping dip surfaces of the quartzite and also the irregularity in vertical distribution which such coarse conglomerates of necessity take.

Perhaps the most instructive section met with in the region is that at the upper narrows of the Baraboo River, where that stream first enters the valley between the two quartzite ranges (Fig. 80). Here the core of the northern range is seen to be composed of vertically placed and shattered ledges of quartzite and quartz-schist, the latter at times showing a very handsome transverse, slaty cleavage. Flanking these on both sides and extending in a thin sheet over most of the top of the range, in places away from the immediate line of section probably completely capping it, and here and there sinking into depressions in the ancient quartzite surface, is the horizontal sandstone. This is a purely quartzose sandstone, at times evenly bedded, at times showing in a striking manner the well known torrential lamination, with few or no quartzite pebbles, and again a fine or coarse conglomerate.

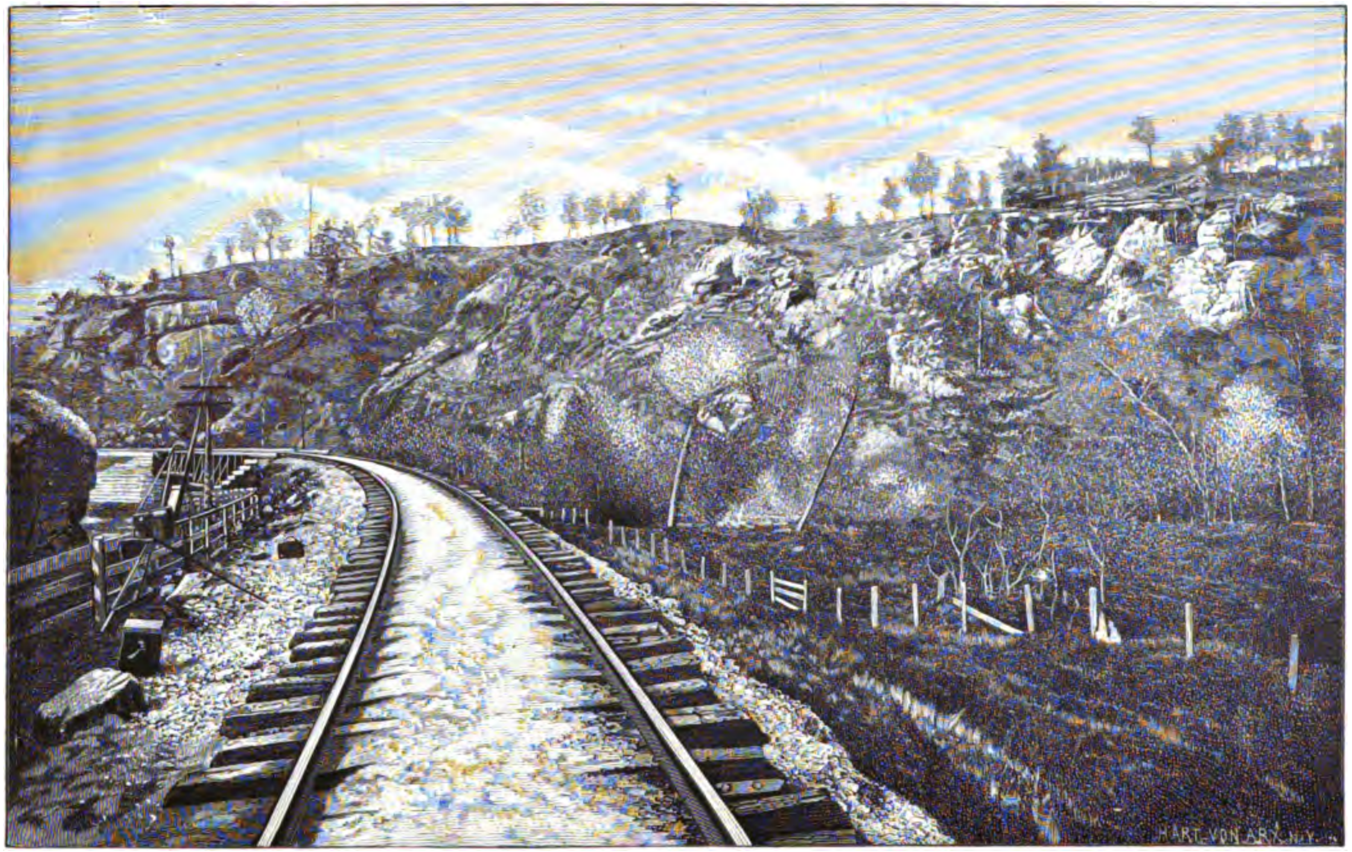
At the southern side of the section, where it comes into contact with the steeply placed and often overhanging cliffs of quartzite, the sandstone includes great masses of this rock varying from a few inches to ten or more feet in length (Fig. 80). At times these masses



... AND HURONIAN Q...

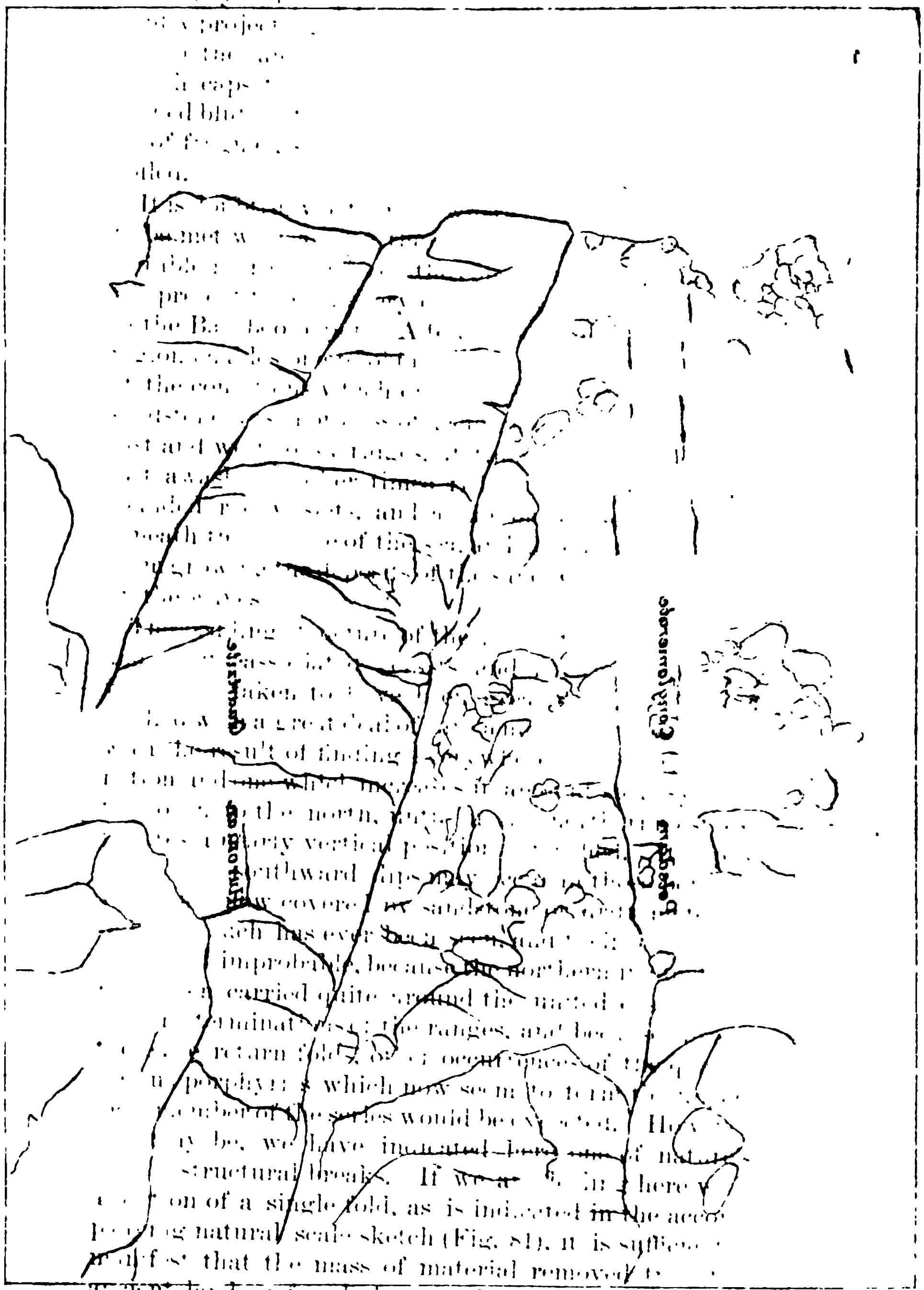


UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND



UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND HURONIAN QUARTZITE.

BOWLDER CONGLOMERATE INCLUDED IN THE POTSDAM SANDSTONE.



...retarn folds, or ... occurrences of ... porphyry which now seem to form ... member of the series would be ... How... ay be, we have indicated here ... of natural structural breaks. If we ... here ... on of a single fold, as is indicated in the acco... ing natural scale sketch (Fig. 81), it is sufficie... manifest that the mass of material removed ... ancient land surface before the deposition upon

[illegible] CONGLOMERATE IN [illegible] IN THE POTSDAM [illegible]

have fallen away from their original positions somewhat, but in other cases they lie nearly parallel to the original bedding, representing evidently projecting and somewhat detached ledges, around which the sandstone accumulated. The conglomerate which caps the range and is shown again in the detached bluff farther north is a much finer material, made up of fragments which have generally been considerably rolled.

FIG. 80. Section displayed to view on the east side of the gorge at the upper narrows of the Baraboo River, looking east. Scale, 750 feet to the inch.

It is doubtful whether anywhere in the world there are to be met with among the ancient formations more admirable reproductions of the conditions which obtain at the present time on every cliffy seashore than are found in the Baraboo region. A few days' examination of this region enables one to obtain a most vivid mental picture of the conditions which obtained at the time when the sandstone was in process of accumulation. He sees great east and west rocky ridges, at times with jagged edges just awash, at other times rising into smoothed and rounded rocky islets, and again buried some distance beneath the surface of the sea, and all about and against them growing the deposits of the sand washed from them by the waves.

The bedding structure of the quartzite of these ranges and of its associated schists and felsitic porphyries, which are taken to have been great eruptive flows, I studied with a great deal of care a number of years since, with the result of finding everywhere a northerly inclination and one which increases in amount steadily from the south to the north, until in the northernmost exposures a nearly vertical position is reached. It is possible that southward dips may occur in those portions which are now covered by sandstone or drift material, but none such has ever been seen, and their occurrence is deemed improbable, because the northern inclinations have been carried quite around the united eastern and western terminations of the ranges, and because, also, if these are return folds, other occurrences of the quartziferous porphyries which now seem to form the uppermost member of the series would be expected. However this may be, we have indicated here one of nature's greater structural breaks. If we are dealing here with a portion of a single fold, as is indicated in the accompanying natural scale sketch (Fig. 81), it is sufficiently manifest that the mass of material removed from the ancient land surface before the deposition upon it of the horizontal

sandstone, if piled again in its place, would rival in elevation the greatest of the existing mountains of the globe.

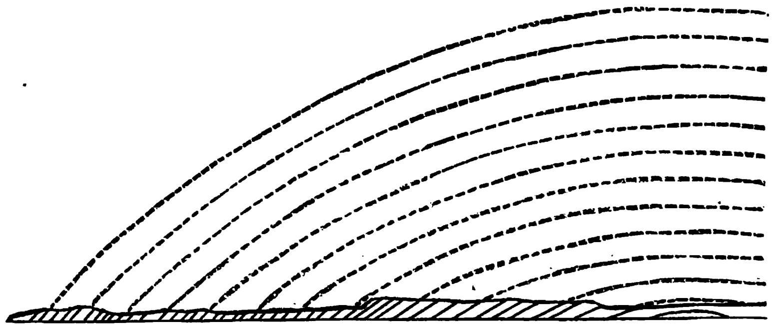
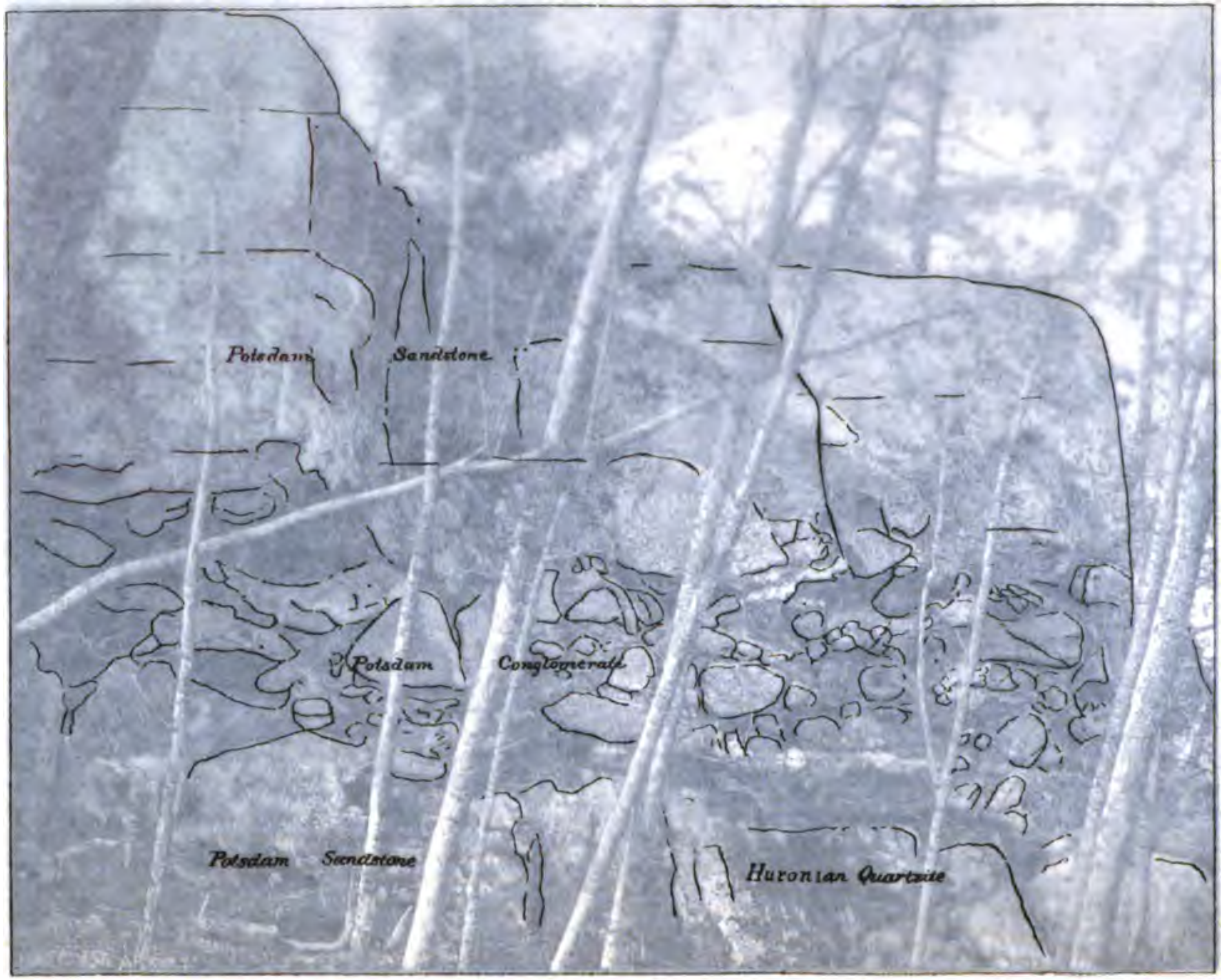


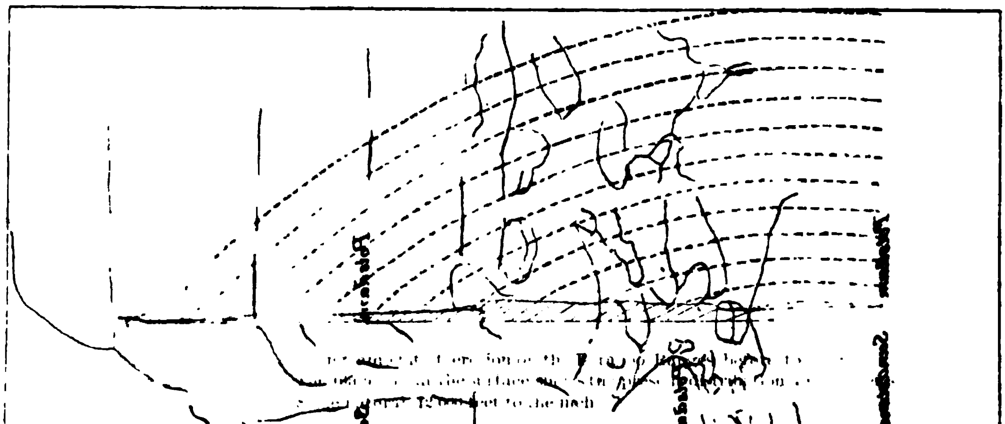
FIG. 81. Ideal section showing amount of erosion of the Baraboo Ranges before the deposition of the Potsdam sandstone. The black line at the surface shows the present distribution and thickness of the Potsdam sandstone. Scale natural, 12,000 feet to the inch.

Although the interval here indicated must have been less than that between the sandstones and the older gneissic formation, which is much more closely folded and deeply altered than the quartzite series, it yet was plainly long enough to cover a period of great orographic movement and a subsequent period when such parts as remained of the mountains formed were almost wholly removed. That such an orographic movement cannot have been merely local is indicated by the magnitude of its effects in this region alone. Indeed these effects are distinctly recognizable in other regions. It must have been the same movement that began the formation of the great bow which the iron-bearing series describes underneath Lake Superior, from the Penokee region on the south to the Animiké region on the north; that folded the cleft slates of the St. Louis and Mississippi Rivers in Minnesota; that produced the crumpling of the same series of rocks in the Marquette and Menominee regions on the south side of Lake Superior and of the same formation in the Vermilion Lake country on the north side of that lake; and that brought into its present condition the original or typical Huronian of the north shore of Lake Huron. The area over which the effects of this one movement may now be traced with a fair degree of certainty is some six hundred miles from east to west by four hundred from north to south. Should we include as an effect of the same movement the gentle bowing of the quartzite formation of southeastern Dakota and southwestern Minnesota, the east and west extent of this territory would be increased by between one and two hundred miles. On a subsequent page it is shown that what are probably effects of the same movement are to be detected over an area several times as large as this.

Notwithstanding all this evidence of a great time interval between the overlying undisturbed Potsdam sandstone and the folded quartzitic or iron-bearing series and notwithstanding the further evi-


Potsdam Sandstone
Potsdam Conglomerate
Potsdam Sandstone
Huronian Quartzite

... in its place would rival in elevation the ... mountains of the globe.



... al here indicated must ... stones and the older ... formation which ... folded and deeply altered than the ... was plainly long enough to cover a period of ... movement and a subsequent period ... such parts ... mountains formed were almost wholly removed. That ... movement cannot have been merely local is ... of its effects in this region alone. Indeed ... are distinctly recognizable in other regions. It must have been the same movement that began the formation of the great trough which the iron-bearing series describes under Lake Superior, from the Penokee region on the south to the Animikie region on the north, that folded the cleft slates of the St. Louis and Mississippi Rivers in Minnesota, that produced the crumpling of the same series of rocks in the Marquette and Menominee regions on the south side of Lake Superior and of the same formation in the Vermilion Lake country on the north side of that lake; and that brought into its ... the original or typical Huronian of the north shore of Lake Huron. The area over which the effects of this one movement ... traced with a fair degree of certainty is some ... from east to west by four hundred ... north ... could we include as an effect of the same movement the ... of the quartzite formation of southeastern Dakota ... western Minnesota, the east and west extent of this territory ... by between one and two hundred miles. On ... shown that what are probably effects of the movement are to be detected over an area several times as ... as this.

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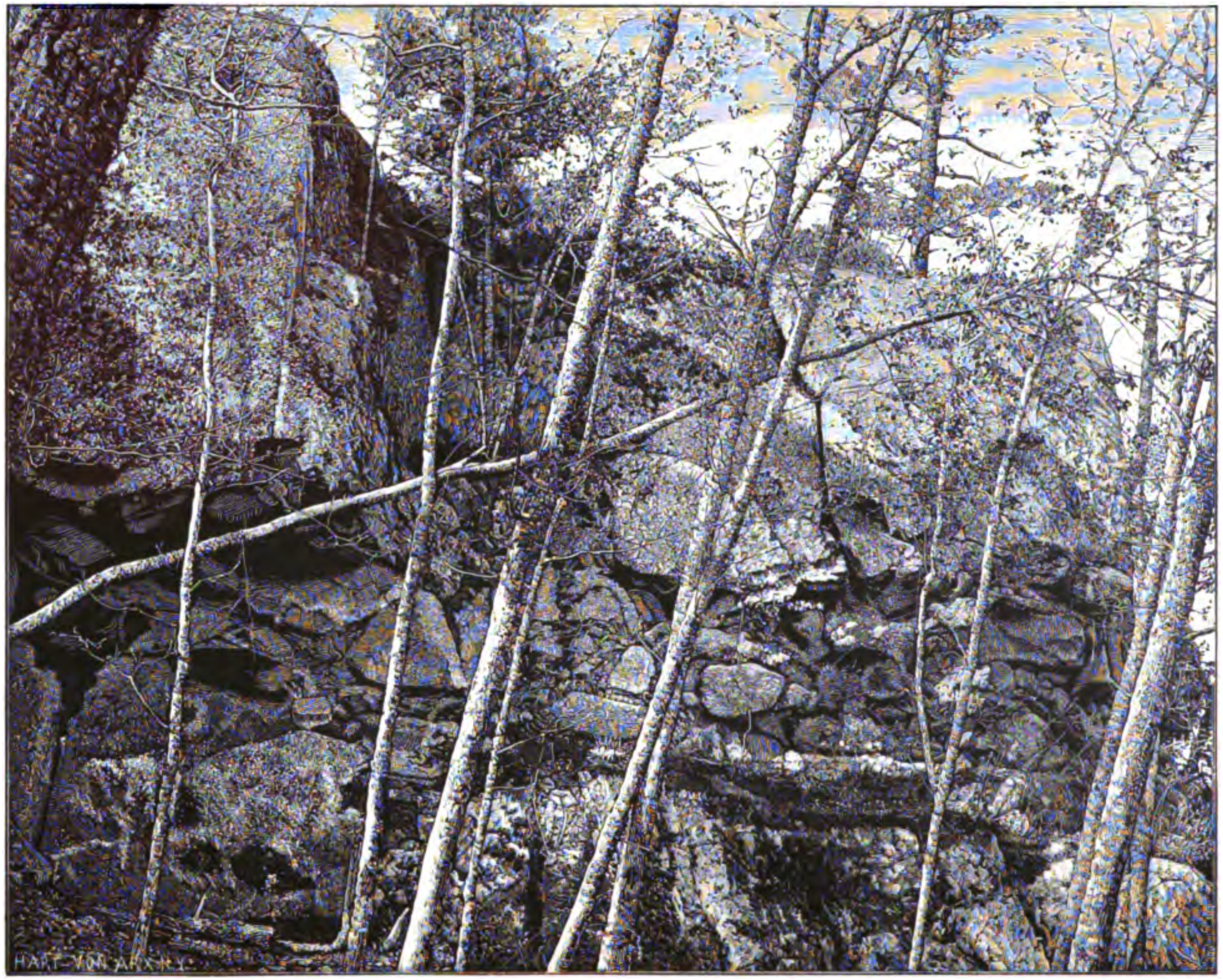
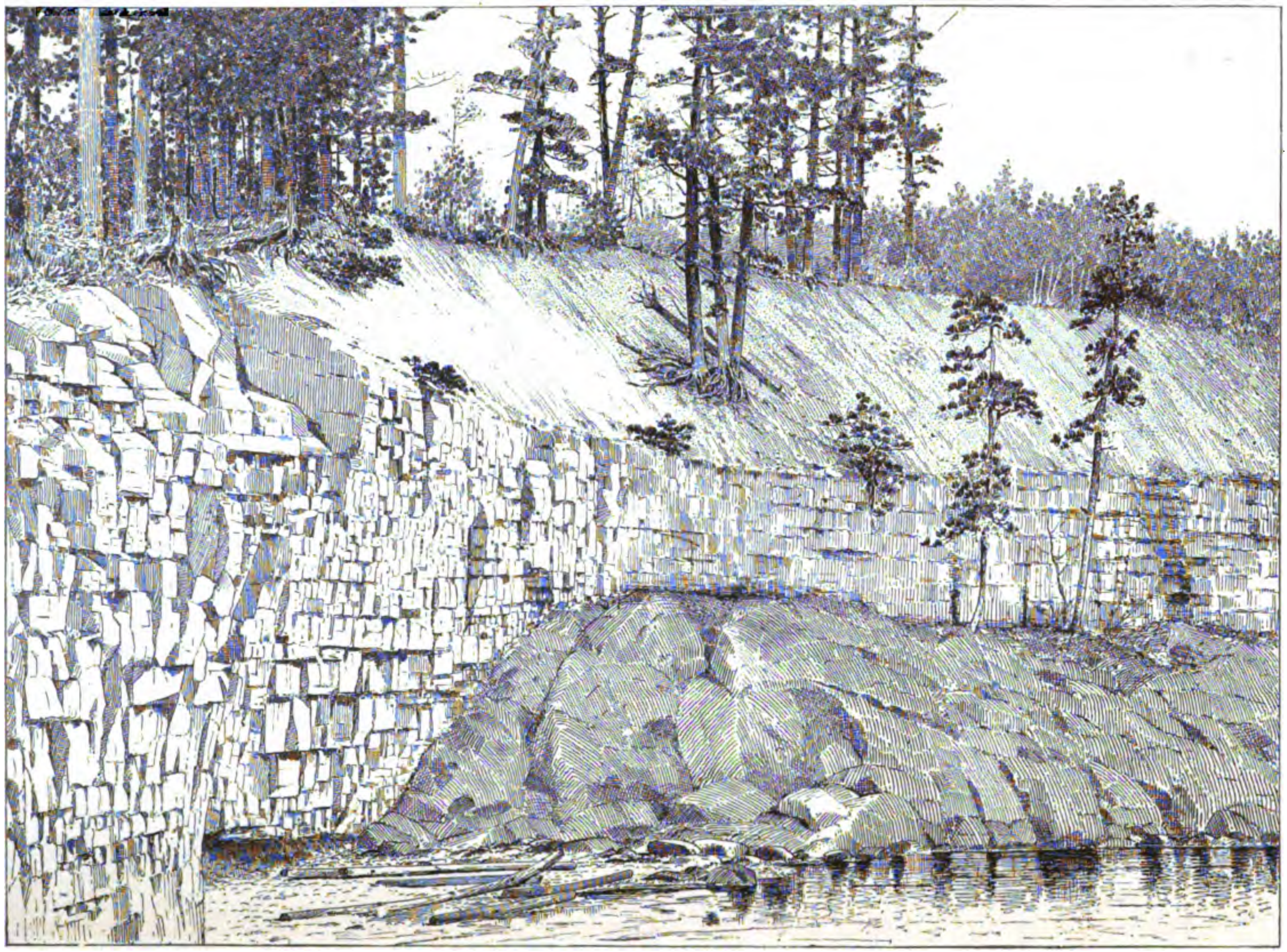


BOWLDER CONGLOMERATE AND PEBBLE CONGLOMERATE OF THE POTSDAM SANDSTONE.



UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND ARCHÆAN GRANITE.

dence of the greatness of this interval to be found in the intercalation between these two series in the Lake Superior region of the great Keweenaw group, certain writers have maintained that both the sandstones and the quartzites underlying them should be counted as belonging to the Cambrian. The argument, so far as there has been any, has been something like this: The overlying undisturbed sandstones carry in the immediate vicinity of their contacts with the quartzite well characterized Pre-Cambrian fossils. The quartzite series beneath is without fossils, but its strong resemblances to the quartzite formation of southeastern Minnesota, in which certain obscure fossil forms have been met with, renders the identity of the two very probable. These fossils have a general resemblance to Cambrian forms. Moreover, no fossiliferous rocks below the Cambrian are known; therefore both formations concerned are Cambrian (Pl. XXXVIII and Fig. 82).

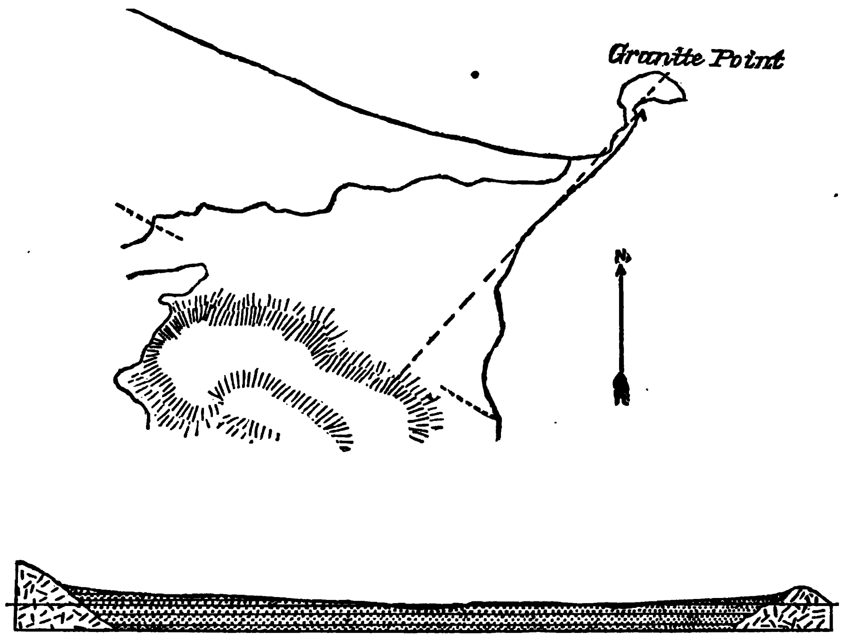


FIG. 82. Map and section of Granite Point, south shore of Lake Superior. Potsdam sandstone lying on an eroded surface of granite, fragments of which are contained in the sandstone.

The equivalency of the quartzite of the Baraboo region with that of southwestern Minnesota is not certain, but, accepting it for the time being, the argument is still fatally defective, since it sets aside the very greatest of structural breaks on the evidence of fossils which might occur anywhere in the geological column, from the Devonian downward, and all of which are fossils to be expected among those formations which antedate the Cambrian.

The sub-Potsdam land surface in the Marquette and Menominee regions of Michigan.—The ancient land surface now referred to is

of course the continuation northward of that just described, but the unconformity here displayed is worthy of separate remark because of the full development of the Lake Superior iron-bearing series, as

FIG. 83. Unconformity between the Potsdam sandstone and Huronian slates, near L'Anse, Mich. After Foster and Whitney.

to whose equivalence with the Baraboo quartzites some doubt might be expressed. The common boundary of the sandstone and crystalline rock areas may be traced continuously in a northeasterly direction from central Wisconsin into the northern peninsula of Michigan, and across that peninsula to the shore of Lake Superior, in the vicinity of the city of Marquette. From Marquette to the head of L'Anse bay this boundary follows closely the coast of Lake Superior, which in several places intersects it, giving fine displays of unconformity along the shore cliffs. Several of these contacts were made classical in geological literature forty years since by Foster and Whitney (Fig. 83), and they are further illustrated here by sketches made from photographs (Pl. XXXIX and Figs. 84 and 85).

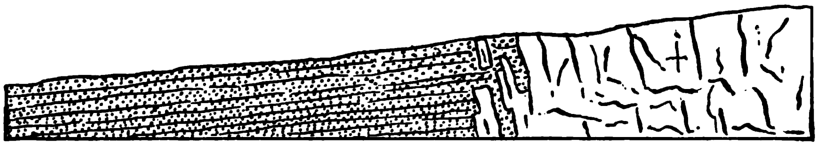


FIG. 84. Contact of Potsdam sandstone and Huronian quartzite, near Marquette, Mich.

As in the case of central Wisconsin, so here, also, numerous isolated outliers of the sandstone formation are met with in the crystalline rock area. In the iron-mining district, in the vicinity of the Menominee River, the boundary between Michigan and Wisconsin, these outliers may be met with in a number of cases in contact with the

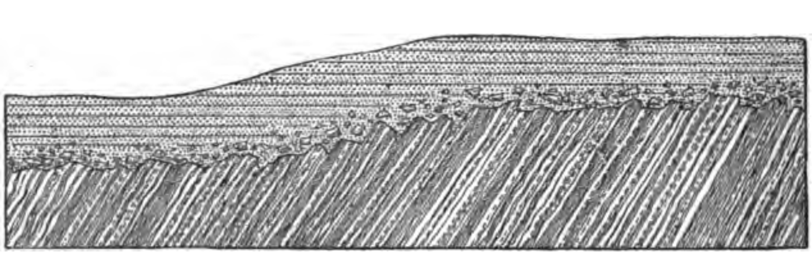
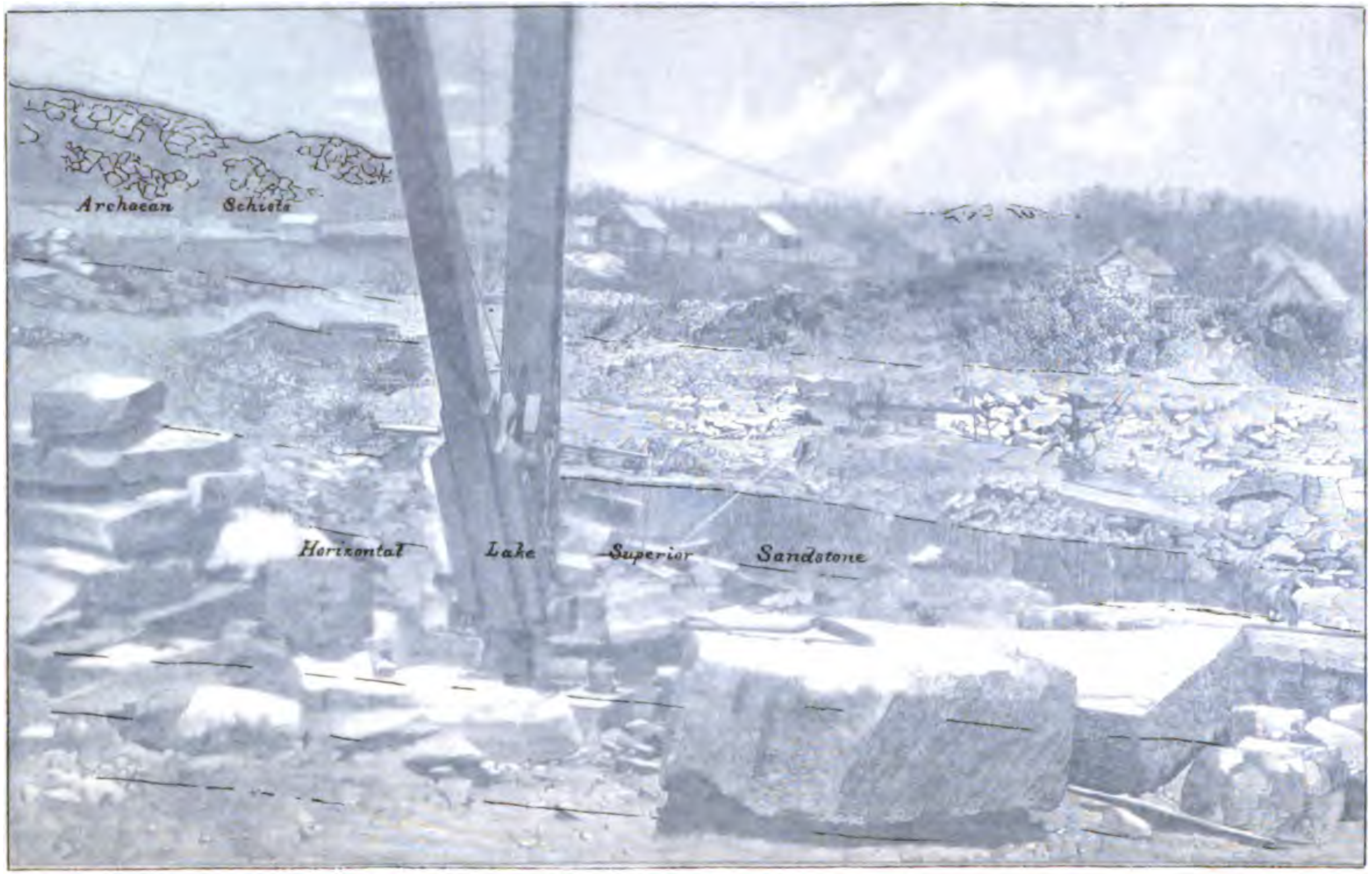


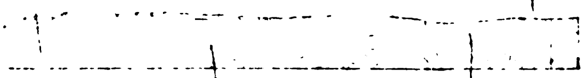
FIG. 85. Section near Norway, Mich., showing Potsdam sandstone overlying the ferruginous schist and ore of the Huronian or iron-bearing series.

tilted layers of the schistose group in which the iron occurs. In several mines, indeed, the iron ore, itself merely an unusually ferruginous portion of one of the layers of the schistose series, is



[illegible] SANDSTONE, MARQ[illegible] MICHIGAN

. . . the . . . that just described . . . the . . . is worthy of separate remark because . . . of the Lake Superior iron-bearing . . . as



. . . sandstone and Huronian slates near L'Anse, Mich.

. . . Baraboo quartzites some doubt might . . . ary of the sandstone and crystal- . . . mounting in a n . . . ly . . . Wisconsin into the northern peninsula of Mich . . . peninsula to the shore of Lake Superior, in the . . . of Marquette. From Marquette to the head of . . . boundary follows closely the coast of Lake Superior, . . . places intersects it, giving fine displays of uncon- . . . cliffs. Several of these contacts were made . . . literature forty years since by Foster and . . . they are further illustrated here by sketches . . . (Pl. XXXIX and Figs. 84 and 85).

Fig. 84. Contact of Potsdam sandstone . . . near Marquette, Mich.

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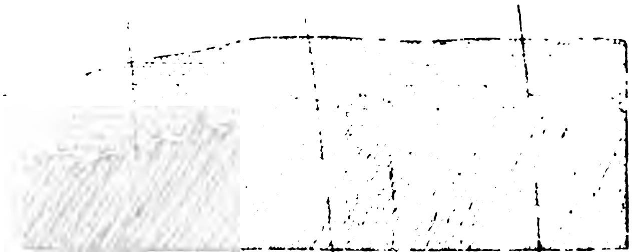


. . . Mich., showing Potsdam sandstone overlying the ferruginous schist . . . bearing series.

. . . layers of the schistose group in which the iron occurs. In . . . mines, indeed, the iron ore, itself merely an unusually fer- . . . portion of one of the layers of the schistose series, is

QUARRIES IN POTSDAM SANDSTONE, MARQUETTE. MICHIGAN.

reached only after the removal of a certain thickness of the unconformably overlying sandstone, in which are buried numerous fragments of the iron schist.

Farther to the northward and westward the sandstone formation is found to traverse indifferently the courses of the various belts of the older gneissic and newer iron-bearing groups. These groups are both closely folded, but the great irregularities of the original surface indicated by the folds are now almost wholly planed off and the sandstone lies upon a relatively level surface. Several sections and views illustrative of the contacts of the sandstone with the two adjacent formations are presented herewith.

The Potsdam-Huronian unconformity of the north shore of Lake Huron.—At Marquette, on the Michigan shore of Lake Superior, the outcrop line of the Potsdam sandstone divides. To the west the sandstone skirts the shore as far as Keweenaw Bay, having immediately behind it a more elevated region, occupied by the higher portions of the ancient basement. To the east of Marquette it forms the shore line all the way to the eastern end of the lake, the older rocks being in this distance wholly concealed by the sandstone formation or by the waters of Lake Superior. The eastern termination of the lake is at the Sault Ste. Marie. A few miles north and again east from this point, however, the basement formations rise again from beneath the sandstone, forming most of the eastern side of Lake Superior and of the northern shore of Lake Huron (Pl. XL).

FIG. 86. Section through Campement d'Ours Island and the northern end of St. Joseph Island, north shore of Lake Huron, looking east. The inclined layers are quartzites and conglomerates of the Huronian; the horizontal layers are the Potsdam and Calciferous below and Trenton above. After Logan.

Along the shore of the north channel of the latter lake, between the St. Mary's and Thessalon Rivers, and for an unknown distance farther eastward, is the series to which the name of Huronian was originally given by Logan and Murray. Everything about this series, as I have argued elsewhere, goes to indicate its identity with the iron-bearing formation of the Marquette region and with the Baraboo quartzite series of central Wisconsin. Great portions of it are made up of indurated sandstones almost identical in character with that of the Baraboo Ranges. It is gently folded.

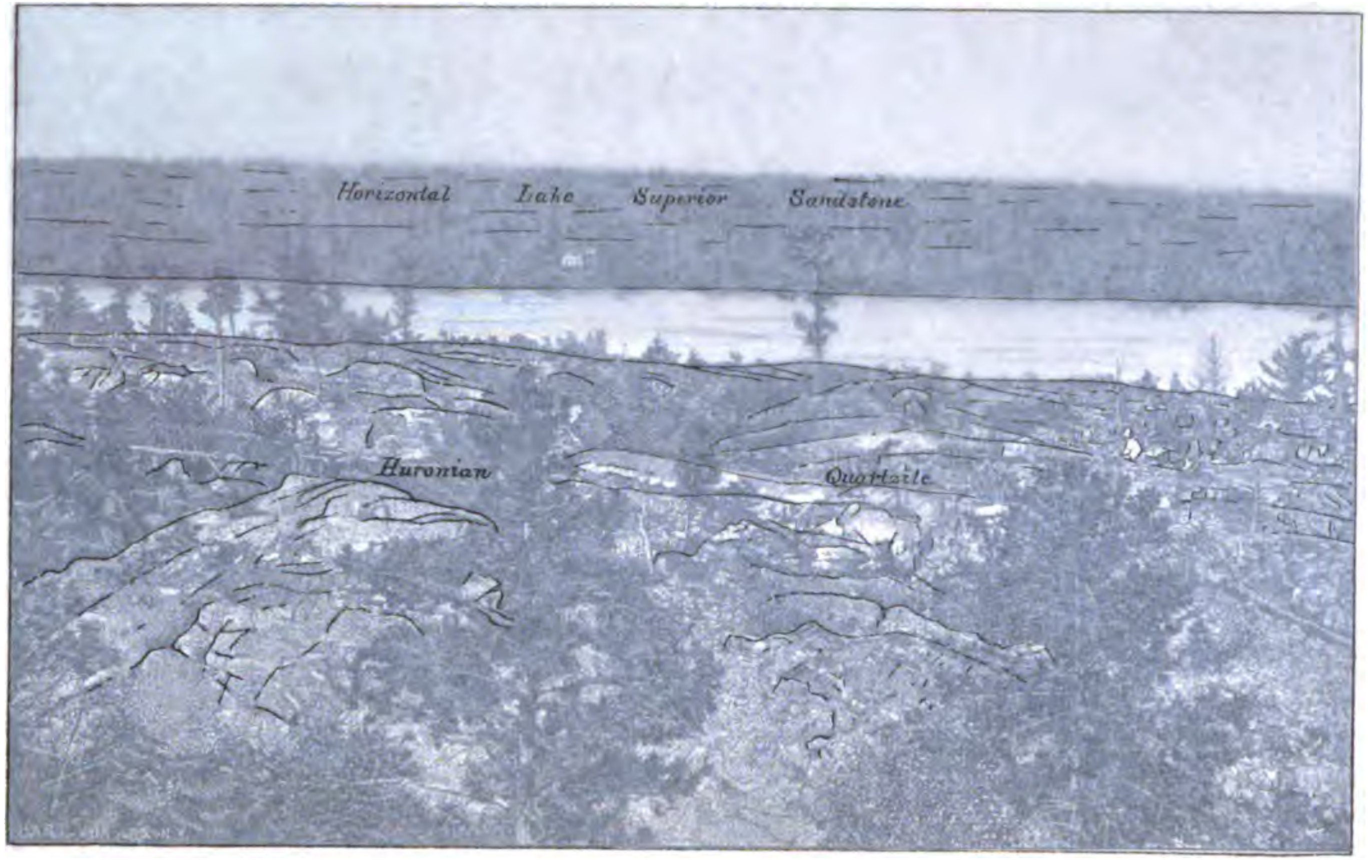
Along the south side of this channel of Lake Huron lies the long string of islands known as the Manitoulin group. These islands are made up of a succession of layers, having a very gentle slope to the southward and ranging from the Potsdam sandstone at the base to the Niagara limestone at the summit. As to their rock structure, these islands are merely a continuation of the belt of country which

may be traced all along the northern and western shores of Lake Michigan. Herewith are reproduced two of Logan's sections traversing the Huronian and the Cambrian and Silurian formations of the Manitoulin Islands (Figs. 86 and 87). They are drawn in both cases to natural scale. Excepting as to the sandstone formation next overlying the Huronian, which Logan regarded as the equivalent of the St. Peter's sandstone of Wisconsin, these sections are exactly as he drew them. The sandstone formation referred to has since been carefully traced through Wisconsin by the Wisconsin survey and through Michigan by Dr. C. Rominger, of the Michigan survey, as far as the westernmost of the Manitoulin Islands, with the result of showing that it represents in fact the Potsdam sandstone and Lower Magnesian limestone of the Wisconsin reports and that the St. Peter's sandstone member is the one that is wanting.

FIG. 87. North and south section through St. Joseph Island and Campement d'Ours Island, on the north shore of Lake Huron. Scale natural, 5 miles to the inch. The Laurentian gneiss (*a*) overlaid unconformably by the folded Huronian series (*b*), which here consists, in upward order, of gray quartzite, altered greenstone, white quartzite, slate-conglomerate limestone, slate-conglomerate greenstone (eruptive), red quartzite, jasper-conglomerate, white quartzite, yellow chert and limestone, and white quartzite and limestone. The Huronian is overlaid unconformably in turn by the Potsdam sandstone and Calciferous (*c*) and the Trenton limestone (*d*).

Here, then, we have the same structural break that is present in central Wisconsin, the sub-Potsdam surface of this region, composed of the deeply truncated folds of the Huronian, being, in fact, the direct eastward continuation of that of central Wisconsin.

The Potsdam-Keweenaw unconformity.—Returning now to Marquette and following the Potsdam sandstone in its western outcrop, we find it, to the west of Keweenaw Bay, abutting unconformably upon still a third formation, the great Keweenaw series, whose relation to the iron-bearing rocks in the Penokee region and in the region of northern Minnesota is such as to render its later origin unquestionable; indeed, it is such as to indicate the intervention, between the periods represented by these two groups, of a period of land erosion. The Keweenaw series then partly fills the great interval which is indicated by the relations of the Potsdam to the iron-bearing series from central Wisconsin to Lake Huron. I say partly, because the structural relations between the Keweenaw series and the Potsdam indicate again a very considerable time-gap. We have followed the Potsdam sandstone westward from Marquette to its abutment against the tilted layers of the Keweenaw series on Keweenaw Point. Following the same formation northwestward from central Wisconsin we find it in the St. Croix River region traversing the edges of the inclined layers of the Keweenaw series, against the tilted layers of which series, moreover, all along the south shore of Lake Superior, from its western termi-



VIEW ON ST MARY'S RIVER.

. . . ng the northern and western shores of Lake . . . Herewith are reproduced two of Logan's . . . traversing the Huronian and the Cambrian . . . formations of the Manitoulin Islands (Figs. . . . and . . .). They are drawn in both cases to . . . Excepting as to the sandstone formation . . . overlying the Huronian, which Logan regarded as the equivalent of the St. Peter's sandstone . . . sections as exactly as he drew . . . The . . . formation referred to has since . . . traced through Wisconsin by the Wisconsin survey and through Michigan by Dr. C. Rominger, of the Michigan survey, as far as the westernmost of the Manitoulin Islands, with the result of showing . . . is in fact the Potsdam sandstone and Lower Magnesian Limestone of the Wisconsin . . . and not the St. Peter's sandstone . . . that is wanting.

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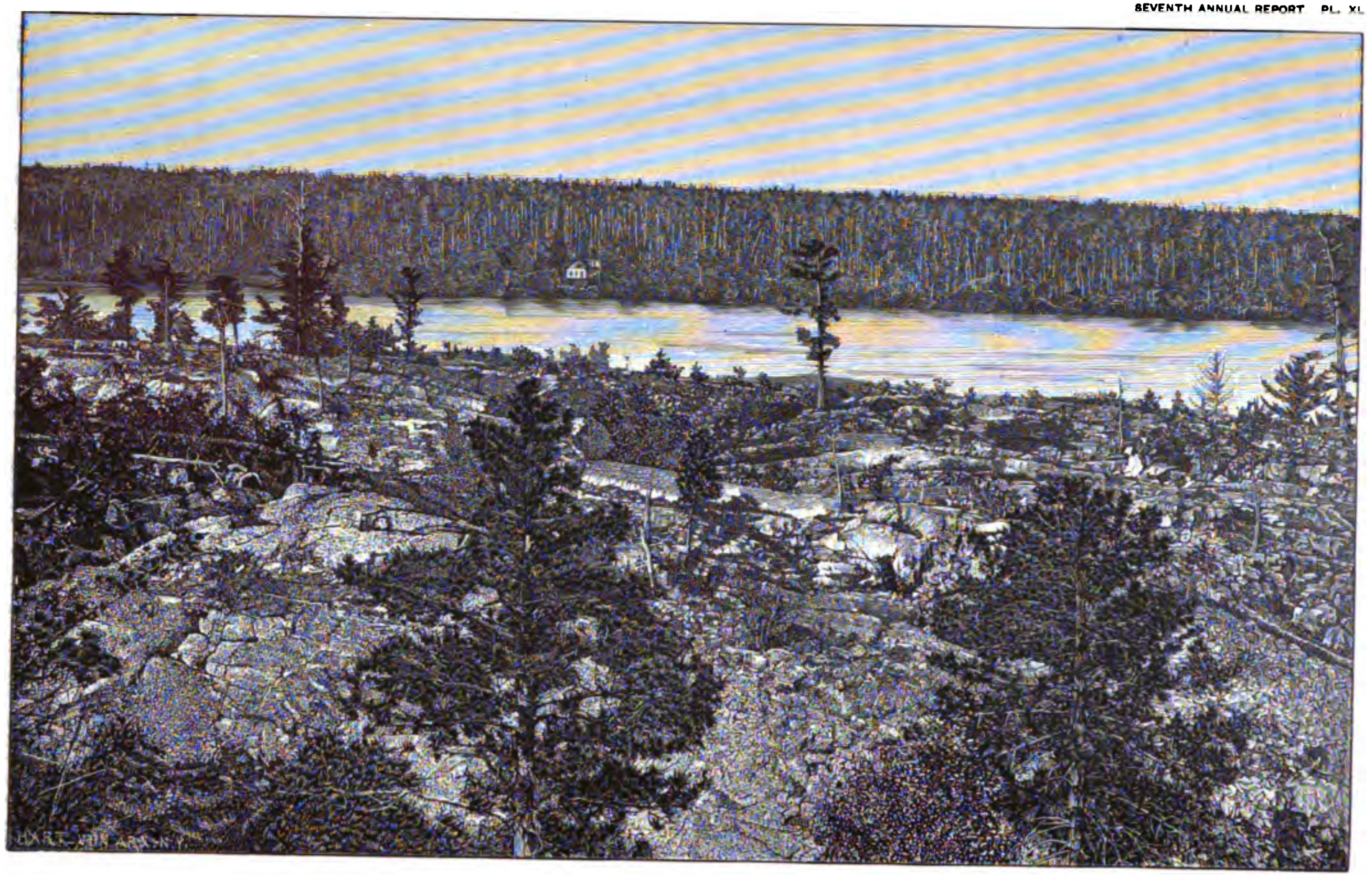


VIEW ON ST. MARY'S RIVER.

nation as far east as the Montreal River, it is found abutting unconformably. A general section in northwestern Wisconsin is indicated in Fig. 88, from which it will be seen, if true conditions are represented, that, subsequent to the completion of the Keweenaw series and previous to the deposition of the Potsdam sandstone, the former was depressed into a great syncline, the whole area then elevated into a land surface, and the sides of the syncline removed, until the whole again became a relatively flat expanse.

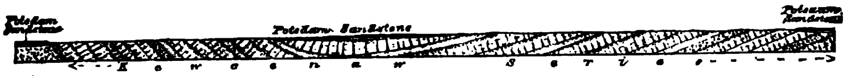


FIG. 88. Section from southeast to northwest in the St. Croix River region of northwestern Wisconsin, through Keweenaw series and Potsdam sandstone. Scale, about 18½ miles to the inch.

Where the sandstone borders the shore of Lake Superior, in the northwestern corner of Wisconsin and again along the south side of Keweenaw Point and thence westward as far as Gogebic Lake, very interesting instances of lateral contacts are met with. These contacts have been described in some detail elsewhere. Here we need merely to say that in each case the contact line follows in a general way the course of a Pre-Potsdam fault in the Keweenaw beds. South of the fault line, in the region of the western end of Lake Superior, and north of it, in the Keweenaw Point region, relatively elevated regions of tilted Keweenawan beds were left by the pre-Potsdam denudation. Subsequently the regions were invaded by the Potsdam sea and the Potsdam sandstone was deposited over higher and lower areas alike. This was followed by the removal of the sandstone from the higher areas, the lower areas, to the north in the one case and to the south in the other, still retaining a part of the thickness of the sandstone covering. The contact lines of the sandstone and Keweenawan areas, which were also the lines of the more ancient faulting, were affected then by some very interesting disturbances in the sandstone at the immediate contact. These disturbances for Keweenaw Point will be found fully described and illustrated in Bulletin 23 of the U. S. Geological Survey, by myself and Professor Chamberlin, where it is shown that, notwithstanding them, the facts observable along these contact lines admit of one interpretation only. It is not desirable to reproduce all of the argument here. We may merely allude to the fact that the sandstone near the contact is crowded with fragments derived from the Keweenaw series in the immediate vicinity of the contact, fragments for which, when we consider their nature, distribution, and arrangement, no other possible source can be found. The similar occurrences in Douglas County, in northwestern Wisconsin, already alluded to, have been described by Mr. E. T. Sweet, in the Wisconsin reports, and are plainly of the same nature and origin as those of Keweenaw Point. The faultings which produced

the fault cliffs against which the sandstone abuts laterally in these two districts were evidently genetically connected with the general synclinal bowing of the entire Keweenaw series.

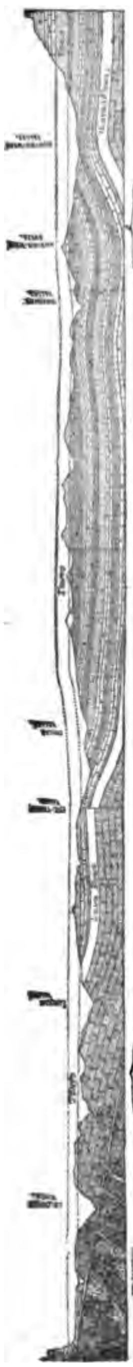


FIG. 89. Section showing the relations of the Tonto sandstone to the Grand Cañon series in the Grand Cañon of the Colorado. After Walcott.

Pre-Potsdam land surface of the Grand Cañon region.—The unconformity which has been shown by Powell and Dutton to obtain at the base of the great conformable pile of Paleozoic and Mesozoic strata, in the Grand Cañon country of Arizona and Colorado, and which has recently been more fully studied and illustrated by Walcott, presents a most striking similarity—in respect both to the nature of the formations immediately above and below the contact and to their structural relations—to the unconformable break just described as obtaining between the Potsdam sandstone and the Keweenaw series in the Lake Superior region (see Pl. XXXIII).

The Tonto sandstone, which marks the base of the horizontal strata, has been shown by Walcott to belong plainly to the Potsdam horizon (Fig. 89). This sandstone traverses the edges of an immense series of gently bowed strata, whose similarity to the Keweenaw series of Lake Superior, to judge from Walcott's descriptions, is very great, inasmuch as it presents a succession of reddish sandstones interleaved with diabasic lava flows. The relation of the Tonto to this series is such as to render evident the intervention between the two of a period not only long enough to cover the folding of the lower series, but the denudation of a pile of strata fully twelve thousand feet in thickness. Yet another similarity between the Grand Cañon section and that of the Lake Superior region is the occurrence of a second great unconformity beneath the Grand Cañon series, below which break is found a great disturbed series of quartzites whose similarity to much of the Lake Superior Huronian is strong.

CASES IN WHICH THE OVERLYING STRATA ARE INCLINED.

If we suppose a depression to take place in the region of an unconformable contact in such manner that the ancient land surface which marks the contact assumes a more or less inclined position, certain difficulties in the way of interpreting the structure may be introduced. If the inclination be but slight and the irregularities of the existing surface be considerable, so that the old land surface is not too rapidly carried

out of sight, the case will be but little different from that where the overlying formation is entirely horizontal. But if the depression has been such as to produce a considerable degree of inclination and the denudation which has produced the present surface has been very deep, the difficulties will be greater. Let us suppose, for instance, a case like that indicated in the accompanying Fig. 90. The strata are now all considerably inclined and it may take some careful observation to establish the break. In forming an opinion as to the structure in such a case we may take into account (1) the relative areal distributions of the several kinds of rocks which make up the supposed discordant formations; (2) the relative lithological characters of the two formations; (3) their relative structural characters; (4) the nature of the minor phenomena of the contact line; and (5) the presence or absence of basal conglomerates.

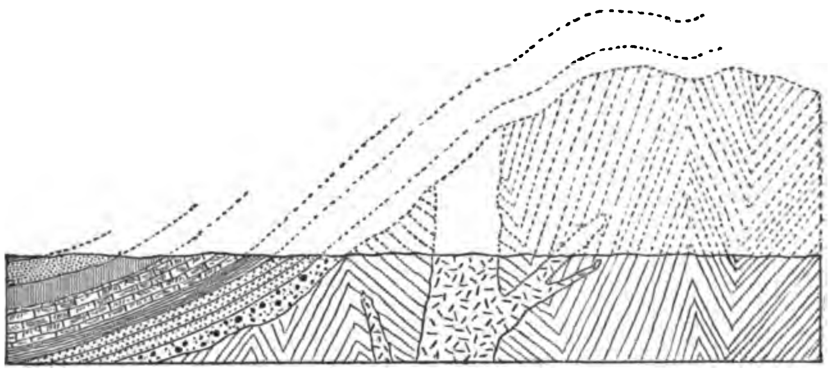


FIG. 90. Ideal sketch of an unconformity where the upper formation is steeply inclined.

Relations of the rock belts of the discordant formations.—Where the formation above an unconformity is undisturbed the true structure is best seen, of course, in an extended vertical section cutting through the upper horizontal formation and into the lower disturbed one. In such a case as that we are now considering, however (i. e., where the overlying strata are considerably inclined to the horizon), the present surface of the country should furnish us with a section corresponding to the vertical one in the former case. In other words, a map of such a region, showing exactly and in detail the distribution of the various rock belts and areas on either side of the supposed line of discordance, should present evidence to us of the existence of the break. This break and the ancient land surface marking it, being the result of an intervening denudation, should intersect the rock areas and belts of the lower formation in such a manner as to indicate plainly to the eye that portions of such belts and areas have been removed. On the other hand, the rock belts of the overlying formation should be free from interruptions other than those incident to ordinary sedimentation. On a subsequent page is given a

brief account of the unconformity of the Penokee region of north Wisconsin and Michigan, accompanied by a map showing the distribution of the rock belts of the region. This map illustrates most beautifully the principle which it is here desired to explain.

Relative lithological characters of the discordant formations.—A pronounced contrast in lithological characters between the two discordant formations is not a theoretical necessity, but it is the ordinary rule, and particularly so in the case of the ancient formations with which we are now particularly concerned. If, in our supposed case of highly inclined but unfolded strata resting against a steeply sloping wall, this wall should present rock-kinds, such as gneiss and other crystalline schists, which have been produced in some way by a profound alteration of sediments, and the overlying formation should show unaltered or relatively little altered kinds, very strong presumptive evidence of the existence of a great unconformity would be offered.

Relative structural characters of the discordant formations.—The lower formation in such a case as we are now supposing would of course be folded, the upper one unfolded, and this difference would constitute the main structural distinction between the two terranes. Cases might arise, however, in which it would be difficult to determine whether the upper formation might not really return at some point beyond the contact line, so as to be folded in with the lower formation. Other minor structural differences which will often present themselves may then be appealed to, and these minor distinctions in any case may often help greatly in establishing the unconformity. While the rock belts of the two formations may, in the neighborhood of the contact line and for the short vertical distance through which it is possible to follow them, show dips and strikes accordant with those of the layers of the upper series, they will more commonly present us with discordances in this respect. These discordances may be seen not only on the larger scale, by comparing the courses of larger belts of the two series, but also in their more minute lamination-structures. In such ancient formations as those which we are especially considering, where there may be a close folding in the lower of the supposed formations, its lamination-structure may well be the result of pressure and may lie quite out of parallelism to the true bedding of the formation; but, even if so, the discordance between a lamination of such an origin and a genuine sedimentary lamination in the formation above the unconformity is strong confirmatory evidence of the existence of the unconformity. The absence of foliation in those masses above the contact line and its presence in those below certainly indicate the production of such a structure prior to the deposition of the upper strata.

Relations of eruptives to the contact of the discordant formations.—It has already been shown how masses of eruptive materal which

antedate the denudation of the intervening land surface in the case of an unconformity are truncated by the contact line. Such interruptions are of particular assistance in determining the structure where the overlying formation is inclined, for under such circumstances they often present great areas to view and may show us extended contacts with the sedimentary rocks of each of the supposed discordant formations. We may suppose, for instance, the case of a great mass of eruptive granite in the folded formation below the break. Where this mass comes in contact with the other rocks of the lower formation it penetrates them intricately in large and smaller branches. Where it is intersected, however, by the contact line and comes in contact with the layers of the upper series, it should show no such penetration, but, on the contrary, should present indications of having been the surface upon which the unfolded strata are deposited.

Minor phenomena of the contact line—basal conglomerates.—In such a case as that now supposed the question might arise as to whether the two great masses of rock on opposite sides of the contact were not brought together by a deep-seated faulting movement. An answer to this question may often be afforded by a close study of the actual contacts of the formations, where they are exposed to view. If a faulting has taken place, this will often be rendered apparent by indications of a sliding movement between the two formations and the consequent shattering of the adjacent rocks. On the other hand, if the contact be one between an eroded surface and the sediment laid upon that surface by the waters of the sea, it should present no indications of such movement and should be expected to show an insertion of the sedimentary material into the irregularities of the surface beneath. Particularly should we expect to find along such a contact, but not necessarily everywhere, fragments of the older rocks embedded within the newer, these fragments ranging perhaps from a fine sand to great angular masses weighing many tons. Such accumulations of detrital material (basal conglomerates) along a contact between two dissimilar kinds of rock are alone enough to indicate a great intervening lapse of time, unless it can be shown that the rock which has furnished them is one which was erupted directly at the surface or one which in some other way may have rapidly reached its present condition of induration and crystallization.

EXAMPLES.

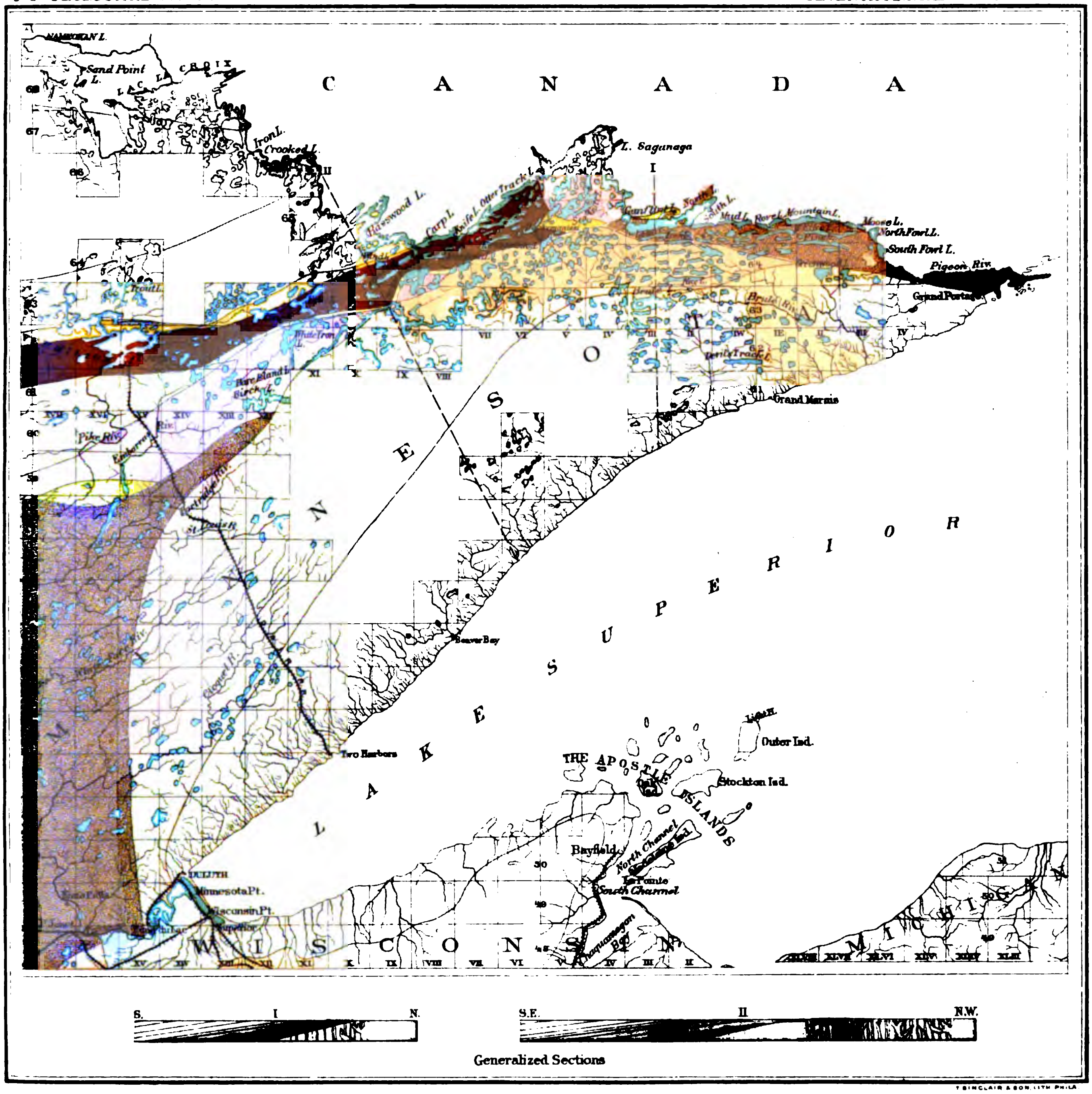
Unconformities between the Animiké series of the north side of Lake Superior and the adjacent formations.—The relations borne by the Animiké series to the older schists and granites of the region north of Lake Superior furnish us with an excellent instance of an

unconformity in which the upper series has been tilted into an inclined position since its original accumulation, but in which the amount of tilting has not been great. In other words, it is a case where the conditions are not greatly different from those obtaining when the upper formation has remained horizontal.

The geology of that portion of the United States lying north of Lake Superior is shown in the map (see Pl. XLI), with its accompanying sections.[1] Since this plate embodies a great deal of entirely new material and since the geology of the area it represents has been hitherto, so far at least as the interior is concerned, largely conjectural, it is desirable that I should give here somewhat more of an account of the structure of this region than would otherwise be necessary.

The latest formation of the region is the Potsdam sandstone, which is in the extreme southwestern corner of the area mapped, in the vicinity of the St. Louis River, between Fond du Lac and Thomson, Minn. The sandstone, here of a generally reddish cast and with a slight easterly dip, may be seen directly overlying a series of folded and cleft slates belonging in the upper part of the Animiké series, as subsequently explained. The contact of this sandstone with the Keweenawan rocks, which are largely displayed in the vicinity of Duluth, is concealed; but in Douglas County, Wis., at a distance of ten or fifteen miles southeast from Fond du Lac, it may be seen in very distinct unconformable abutment against the Keweenawan diabases of that district. Farther east the entire coast

[1] This map embodies in a condensed form the hitherto unpublished results of a large amount of study in the field. Heretofore, except along the immediate coast of Lake Superior, no attempt has been made to map this region otherwise than in the most general manner. Indeed, being a complete wilderness it has been geologically for the most part a terra incognita. Portions of the ancient canoe route along the national boundary line have been followed several times during the last sixty years by different geologists (Bigsby, Bell, Norwood, and N. H. Winchell) and the results of their desultory observations have been published in the form of itineraries. Similar publications have been made of observations made along two or three routes in the region between the boundary and the coast of the lake by N. H. Winchell and W. M. Chauvenet. A summary account, with outline map and sections, embodying all of the results in this region to date, was prepared by myself in 1881 (Monograph of the U. S. Geological Survey No. 5, published in 1883), and some of the results of the field season of 1883 were announced in a preliminary paper on an investigation of the Archæan formations of the Northwestern States, published by myself in the Fifth Annual Report of the U. S. Geological Survey, the preparation of this paper and of the map accompanying it dating from June, 1884. In the years from 1883 to 1886, aided by Messrs. Merriam, Chauvenet, and Williams, I have been engaged in a general exploration of the interior part of this region, particularly in portions hitherto entirely unknown, in which work Mr. Merriam has had the largest share, the lengths of his lines of travel, not counting minor irregularities and repetitions, aggregating to date (July, 1886) something like fifteen hundred miles. The work in this region is still in progress, but has now advanced far enough to justify the publication of this preliminary map.



CAMBRIAN: Potsdam Sandstone

KEWEENAWAN: Olivine Gabbro (Basal); Remainder of Keweenawan Series

HURONIAN: Animike Series; Vermilion Lake Iron bearing Series

LAURENTIAN: Green Schists; Mica-Schists with Granite veins and areas; Granite

The color for the Vermilion Lake Iron-bearing Series is supposed to cover also some older schists

In the two western areas of granite there are included a few small patches or remnants of mica-schist or gneiss.

GEOLOGICAL MAP OF NORTHEASTERN MINNESOTA

JANUARY 1886.

of Lake Superior, to within two miles of the mouth of the Montreal River, on the boundary line between Michigan and Wisconsin, is formed of the same sandstones in horizontal position.

Unconformably beneath the Potsdam sandstone comes next the great Keweenaw series, which in this region reaches an aggregate thickness of upward of twenty thousand feet, the layers being mainly of an eruptive origin, but also in part of a detrital nature. The upper detrital division of the Keweenaw series is, however, not represented in the region, being buried here beneath the waters of Lake Superior. So far as the coast line of the lake is concerned, the characters and divisions of the Keweenawan rocks there displayed I have set forth in another publication.[1] It will only be necessary here to recapitulate some of the most prominent characteristics. In a general way it may be said that the beds of this series have throughout their extent in northeastern Minnesota a flat dip toward Lake Superior, or in a southeasterly direction. When, however, we examine the structure more closely we discover that there is a variation in the amount of dip, from 45° (which high figure is reached only in the immediate vicinity of Duluth) to approximate horizontality, and in the direction of dip from due east to due south. These variations in the amount and direction of dip, however, are not irregularly distributed. The due eastward dips obtain at the western extremity of the coast line, whence, as we follow the layers of the series eastward, the direction of the dip is found to turn more and more to the south of east, until, midway the course of the coast, it is due southeast, or directly at right angles to the coast line, and at the eastern end of the Minnesota shore is due south. Thus it follows that the outcrops of the layers or groups of layers make a series of crescentic and concentric belts whose radii are smaller than that of the coast line itself. A complete ascending section of the series, so far as it is developed in this region, may, then, be obtained by crossing the country in a southeastward direction from the vicinity of Kekekabik Lake to the mouth of Temperance River, or by following the coast line northeastwardly from Fond du Lac to the same point. A third section may be obtained by proceeding along the coast from Grand Portage Bay southwestwardly to Temperance River, but this section will be less complete than the others, partly because of the fact that some of the members of the section developed farther east are not here represented and partly also because the lowermost members of the series do not reach the coast in this distance.

In the case of either of the more complete sections we find at the base of the series an immense development of stratiform, fresh, and often exceedingly coarse olivine gabbros, the individual layers of

[1] Copper-Bearing Rocks of Lake Superior, Monograph of the U. S. Geological Survey No. 5, pp. 260–328 and Pls. I–III, V–XV, XXVI–XXIX.

which, notwithstanding their complete crystallization, very coarse grain, and lack of amygdaloidal or dense upper surfaces, seem evidently to have formed great flows at the surface of the region as it stood at the time of their extrusion. Next to the belt of country occupied by these olivinitic gabbros follows a belt in which non-olivinitic gabbros are confusedly mingled with intrusive, reddish, acidic rocks of several kinds. These are the rocks exposed on the hills at Duluth, Minn. At some little distance west of the place the lower olivinitic gabbros are in sight. The lower one of these gabbro belts receives a separate color on the accompanying map, the upper one being covered by the same color that spreads over the remaining layers of the Keweenawan series. These remaining layers are made up in their lower portions of a succession of heavy, but sharply defined beds of very fine-grained diabases and diabase-porphyrites, with some interleaved detrital matter and with thin amygdaloids, capping many but not all layers. Next follows a series of heavy, fine-grained, brown diabase-porphyrites, along with some intrusive, acidic, reddish porphyrites. All these layers bear a distinct resemblance to the rocks which occupy a corresponding horizon in the Bohemian Range of Keweenaw Point. There is then a succession of relatively very thin flows, composed mainly of a fine-grained, olivine-bearing diabase or melaphyre having a very highly vesicular, stratiform amygdaloid, with a number of thin seams of reddish sandstone. Above this comes a series marked by the predominance of dark, olivine-bearing gabbros without amygdaloids and by the great abundance of interleaved and intrusive, red, acidic porphyrites. Finally the uppermost layers of the series, as here developed with a thickness of two to three thousand feet, are very distinctly bedded, fine-grained diabases and melaphyres with strongly developed amygdaloids and a considerable quantity of interstratified sandstone and conglomerate. These layers in turn bear a striking resemblance to those which make the upper portions of the eruptive division of the Keweenaw series of Keweenaw Point.

Next in downward order comes the Animiké iron-bearing, slaty series, whose relations to the adjoining formations it is now designed especially to set forth. The Animiké rocks are exposed in four distinct areas, one of which is separated from the others by an overlap of the great gabbro which forms the base of the Keweenaw series. The others are separated from one another, so far as known, by drift covering only. The first of these areas is that which, with its principal development in Canada, along the shores of Thunder Bay, crosses into the United States in northeastern Minnesota, the national boundary line being within this formation from the outlet of Gunflint Lake eastward to the eastern extremity of Pigeon Point. Around Thunder Bay the rocks of this series, which are chiefly black slates, graywackes, argillaceous quartzites, interstratified diabase, and

gabbro layers, which are many in number and individually often have a considerable thickness, are exposed on a large scale. Immense dikes of gabbro and diabase also penetrate these layers, the gabbro dikes, which are at times several hundred feet in thickness, being noticeably much closer in character to the great gabbro at the base of the Keweenaw series than to those gabbros which are interleaved with the Animiké slates.

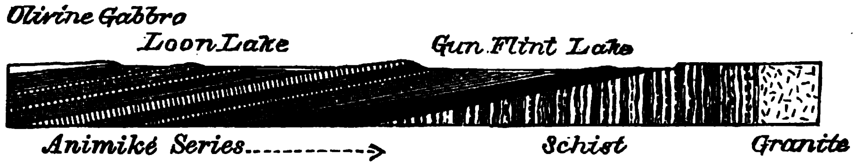


FIG. 91. Section across Gunflint and Loon Lakes, on the national boundary line. Designed to show the relations of the Animiké series to the older schists and granite and to the newer Keweenawan gabbro. Scale, 1 mile to the inch. The black bed at the base of the Animiké is the ferruginous horizon. The remainder of the Animiké in the section is composed of slates and slaty quartzites, with interstratified greenstones.

In the vicinity of Thunder Bay the Animiké rocks are often nearly horizontal, but show a general tendency toward a southeastward inclination. As the formation crosses into United States territory it shows more marked inclinations, which average probably about ten degrees, though at times less than this, and sometimes reach as much as twenty degrees. The national boundary line is situated within this formation from the mouth of Pigeon River to Gunflint Lake; but on the north side of the latter lake, and again to the north of the next lake to the east, called North Lake, the unconformable abutment of the Animiké series against an older formation of granite and schists is very handsomely shown. The actual contact of the two formations is not seen, but the exposures approach to within a few feet of each other and the relative attitudes of the two formations are such as to leave no question whatever with regard to the unconformity. Not only is this shown by the vertical position of the schists as contrasted with the flat inclinations of the slaty series, but also by the way in which the latter beds, to the north of the two lakes mentioned, fit into the sinuosities of outline of the older formations. The entire contrast as to lithological characters between the two sets of rocks furnishes further proof. A north and south section midway in Gunflint Lake is given herewith to illustrate these relations (Fig. 91). So far as it is developed along the national boundary line the lowest layers of the Animiké series in sight are those on Gunflint Lake. The highest layers are those in the vicinity of Grand Portage Bay, the whole succession between these points being some thousands of feet in thickness. The iron-bearing horizon at the base of this succession is lithologically identical with that of the Penokee series of northern Wisconsin and Michigan, while the black slates, graywackes, etc., which succeed the iron-bearing horizon, are in turn

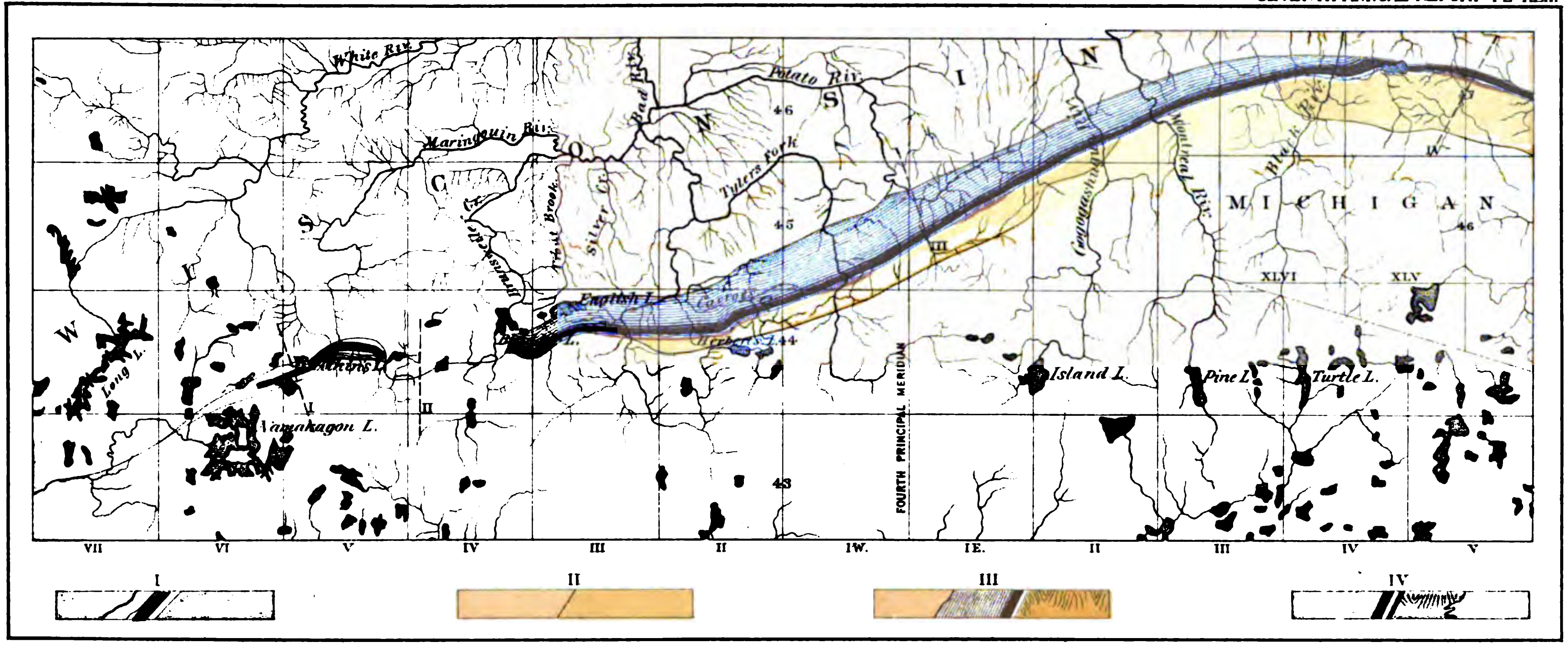
the counterparts of those which form the middle and upper portions of the Penokee series. The interstratified gabbros of the Animiké are wanting, however, or are relatively rare in the Penokee region.

In attempting to trace the Animiké rocks from this area farther west and southwest we find ourselves constantly balked by the overlapping layers of the Keweenaw series. This overlap will be best appreciated on an inspection of the accompanying map (see Pl. XLIII), upon which it is shown that the basal olivine-gabbros of the Keweenaw series entirely cut out the Animiké in its surface distribution, coming, a few miles to the west of Gunflint Lake, directly into contact with the older schists. Continuing southwest, now, nothing further is seen of the flat-lying Animiké beds for over fifty miles, but in the vicinity of the south side of Birch Lake they emerge from beneath the overlapping gabbro. From here the lower members of the series, with the usual flat southeasterly dip and with the lithological characters well preserved, may be traced along the south side of the Mesabé granite range as far as the Embarrass Lakes, a distance of some twenty-five miles, in which distance they are plainly in unconformable abutment upon the granite to the north. After this they are concealed entirely, so far as present knowledge goes, by the immensely heavy drift-covering of the region, until the vicinity of Pokegama Falls, on the Mississippi River, is reached, some sixty miles farther to the southwest. Here the basal layer of the Animiké is a reddish quartzite, followed by and associated with layers of cherty iron ores, like the remaining ones of the Animiké series. These layers dip at the usual flat angle to the southeast and rest unconformably upon gneiss and granite, which are plainly the direct continuation of those of the Mesabé Range.

Southward and eastward of the line from the Mesabé Range to Pokegama Falls the rocks are mainly concealed by swamp or heavy drift covering, but a great display of the upper portions of the Animiké series is seen again along the St. Louis River from Knife Falls to Thomson, where they are cleft and folded argillaceous slates. Farther south and west these slates may be traced into continuity with mica-schists, which, on the Mississippi River in the vicinity of Little Falls, are staurolitic and garnetiferous. These upper horizons of the Animiké are the counterparts of the upper horizons of the iron-bearing series in the Penokee region and again in the Marquette region of Michigan.

The Animiké rocks of this region are thus unconformably placed upon an older series of schists and granite and lie unconformably beneath the newer Keweenaw series, the latter unconformity being indicated by the manner in which the basal beds of the Keweenaw series traverse the courses of those of the Animiké and by the folded condition of the Animiké slates in the vicinity of the St. Louis River.

KAKABIKKA FALLS, KAMINISTIQUIA RIVER.



KEWEENAWAN

HURONIAN

Greywacke & Black Slate member

Iron-Bearing member

Siliceous Slate member

Limestone & White chert member

LAURENTIAN

Granite and Granitoid Gneiss

Hornblende-Schist, Chlorite Schist Mica-Schist & Schistose Gneiss.

Scale of Map

Scale of Sections

GEOLOGICAL MAP OF THE PENOKEE-GOGEBIC IRON REGION.

The crumplings in this case have plainly preceded the accumulation of the Keweenawan beds.

Finally, northward from the outcropping edges of the Animiké series the country is everywhere occupied by belts of closely folded slates and schists, between which are great areas of granite. A part of these schists, with the granite, makes up the older basement upon which the Animiké rests. Another part, made up of slates and other fragmental rocks and carrying great thicknesses of ferruginous material, is taken to be the same as the Animiké itself, as is further argued on a subsequent page (Pl. XLII).

Unconformities of the Penokee-Gogebic region of northern Wisconsin and Michigan.—No other so striking example of unconformity between a series of highly tilted but unfolded strata above the break and a deeply folded series below as that afforded by the Penokee region is known to the writer. Indeed, there are in this region two notable stratigraphical breaks: one between the iron-bearing series and the folded gneissic formation to the south of it; another between the unfolded but inclined iron-bearing series and the equally highly inclined Keweenaw series to the north. These breaks and the terranes which they separate are the counterparts of those just described as obtaining north of Lake Superior.

The accompanying map (Pl. XLIII) shows the distribution and structural relations of the several formations and the several principal kinds of rocks in this region. The Keweenawan and iron-bearing series both being highly inclined, the map is in fact what the vertical section is where the upper strata of an unconformity are still essentially horizontal. The region is one which is only now beginning to be at all easy of access and it is still in the main covered with a dense forest growth. Notwithstanding these difficulties and the further difficulty that in places the drift covering is considerable, the general structure of the region has been by a great deal of painstaking labor very thoroughly worked out.

The lower one of the two unconformities of this region—i. e., that between the gneissic formation on the south and the iron-bearing series next north of it—is indicated in the first place by the manner in which the belts of the former series are traversed and interrupted by the continuous belts of the upper formation. This relation is beautifully shown by the map (see Pl. XLIII) which indicates the distribution of the several rocks of the region, and this distribution is alone enough, considering the kinds of rock of which the lower series is composed, to indicate the existence of the unconformity. If the gneisses, schists, granites, etc. to the south of the break, after having been deeply cut by atmospheric denudation, had formed the sea-bottom upon which the iron-bearing series was piled by the ordinary processes of sedimentation, the relations would be precisely such as obtain here. Lest it might be argued that the

various rock masses here included under the general designation of gneissic formation may have had an eruptive origin, and therefore an irregularity in distribution, so that the base of the iron-bearing series comes necessarily into contact with different kinds in different places, I may say that, even should we accept an eruptive origin for these rocks, an unconformity is still demonstrable. If eruptive, these southern rocks have certainly not been extruded subsequently to the deposition of the beds of the iron series. Had they been so extruded, it is inconceivable that a series of eruptions different as to materials and times of extravasation should all have stopped so near to one geological horizon. On the contrary, some of them would have deeply invaded the iron-bearing series. But of such an invasion no sign whatever is to be seen, either in the geographical arrangement of the different kinds of rock, as shown by the map, or in the minor structural details observed at the contacts of the two formations. Moreover, the basal beds of the iron series contain abundant fragments derived from the more southerly granites, gneisses, and schists. It is thus plain that the southerly rocks have formed the basement upon which the iron-bearing series was built. Sediments may of course be piled upon a basement of eruptive materials of essentially the same geological age, but the case we are considering here finds no parallel in such occurrences. The gneisses, schists, granites, etc. forming the supposed eruptives are, if eruptive, certainly not to be compared with the lavas of modern times. On the contrary, their completely crystalline character and general structure would force us to believe that they solidified far within the depths of the earth, and that therefore, before they reached the surface of the bottom of the sea upon which the slate beds were accumulated, the whole region in which they occur must have been subjected to an enormous atmospheric erosion. There is here, then, a genuine geological break, even in the view that the more southerly rocks are all eruptives. But an eruptive origin for all of these rocks, thus admitted for the moment, is by no means accepted as true. The granites of the gneissic series plainly are of eruptive origin. This is made manifest by the way in which they intersect the associated schists at their contacts with them. The gneisses and schists of the series, however, are in part at least of a sedimentary origin. Some of the schists particularly retain traces of their former fragmental texture, though now mainly made up of material which has crystallized in situ. If these gneisses and schists be in any measure of sedimentary origin, then of course they passed through immensely prolonged processes of dislocation, alteration, and erosion before the deposition upon them of the earliest member of the overlying series.

The closely folded and crumpled condition of the gneissic series as compared with the unfolded condition of the iron-bearing series affords, of course, another argument in favor of the existence of the unconformity.

A furtner proof of the entire discordance of the two sets of rocks is afforded by the striking contrasts they present in lithological characters. This is particularly shown by the very different degrees of alteration that the two series have undergone. The once possibly fragmental sediments of the lower series are now completely crystalline, while the eruptives of the series have generally undergone most profound metasomatic change. In the upper series, on the other hand, the retention of the fragmental character is the rule and the eruptives are all of a basic character, while all of the crystalline material met with in the rocks of the series that is not referable to solidification from a molten state or to direct chemical deposition is distinctly traceable to merely metasomatic change. The rocks of the upper series are not properly crystalline schists. Those of the lower series are crystalline schists in the fullest sense of the term.

Yet another proof of unconformity is afforded by the contrast between the contacts of the granite masses of the lower series with the schists of the same series and the contacts of the same granites with the basal member of the iron-bearing formation. As already said, where the granite meets the lower schists it intersects them intricately, but where the basal beds of the iron series lie against the granite they are never penetrated by granite veins, but, on the contrary, show every evidence of having been deposited upon the granite surface.

A yet further proof is found in the discordant laminations of the two sets of rocks, when seen in contact or close proximity. This discordance is at times very marked, while in other places there is a near approach to parallelism in strike and dip of the lamination-directions of the two formations. In the newer slate and iron-bearing series the lamination, always plainly the result of sedimentary deposition, conforms of course to the general courses of the rock belts of the series, and since these courses vary considerably, as indicated on the accompanying map, the lamination-directions vary also. Hence follow discordant laminations in the vicinity of some contacts and accordant ones at others, which is precisely what we should expect along an unconformable contact line. It is no argument against this conclusion to maintain that the lamination of the older set of rocks is in this case what is known to geologists as foliation, and not the result of sedimentation. It is probably commonly foliation, that is, a structure in some measure due to the intense squeezing which the older schistose series has undergone, and very often probably occupies a position quite oblique to the original bedding directions, but it is plain that it must have been produced before the deposition of the first of the overlying slaty rocks, for otherwise the latter must have been affected also by a foliation similar in character and direction. The occurrence of foliation on one side of a contact line and its absence on the other, where this contact is one between two great

and dissimilar sets of rocks, are strongly suggestive of the existence of a great structural break. It should be said that the discordance of lamination is not made out only from closely approximated exposures, but also from actual contacts, where the basal layers of the slate series may be seen to traverse the edges of the laminæ of the older formation at a considerable angle.

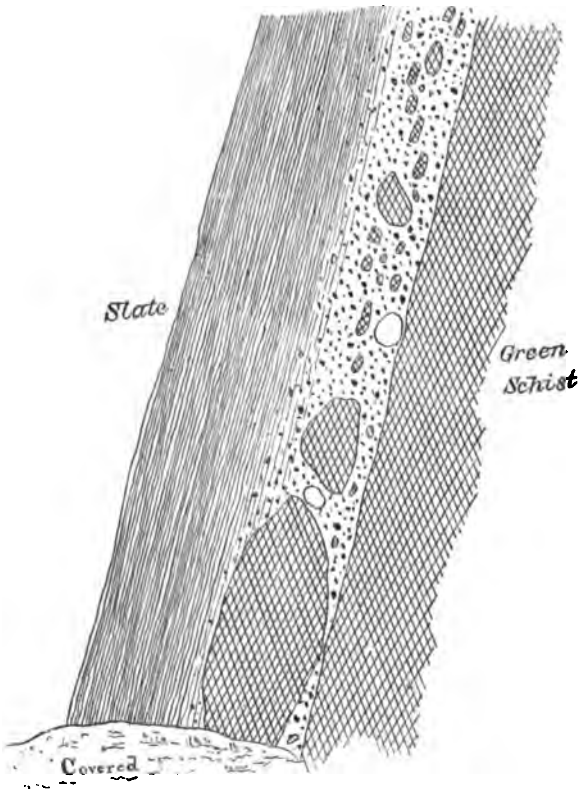


FIG. 92. Sketch showing basal conglomerate at the contact of the iron-bearing series and older schists, Potato River, Wisconsin.

Finally, a convincing proof is found in the occurrence of finely developed basal conglomerates at the contact of the two formations. There are several points along the contact line where one may pass within a few steps from ledges of gneiss or schists of the older formation to others of the lowest member of the newer, the latter being crowded with fragments derived from the older rock. Even the matrix portion of the rock is composed of gneissic or schistose detritus, while a few steps farther away from the contact it has graded into an ordinary quartzite or slate. The most interesting occurrence of this kind is that met with on the gorge of the Potato River in the western part of T. 45 N., R. 2 E. of the fourth principal meridian, Wisconsin, where that stream intersects the contact of the two

formations. The eastern side of the ravine presents good exposures of the lower 500 feet of the iron-bearing series and also of the schists below. At one point on the ravine side a cliff about thirty feet in height shows, obliquely traversing its face at an angle of about 45° with the horizon, the junction of the basal member of the iron-bearing series and a green schist of the lower series. The true inclination of the junction is 70° to the northwestward, the apparent lower figure being produced by the acute angle which the cliff face makes with the general strike direction. The greenish, chloritic, schistose rock of the lower series at the contact is a very profoundly altered greenstone or basic eruptive. Its very strongly marked schistose structure inclines southward, making a right angle with the contact line. Reposing directly against the wall of schist may be seen several hundred feet in thickness of a slate or slaty quartzite, whose laminæ are in general parallel to the contact line. The lower sixteen inches to two and one-half feet of this slate is a finely developed basal conglomerate, including great fragments of the greenish schist, which at times reach dimensions of five by two and one-half feet in size. Fragments of all sizes of the schist occur and the matrix of the conglomerate is plainly composed largely of a fine material of the same derivation. Fragments of other rocks, such as white quartz, at times as much as eight and ten inches across, also occur. These pebbles show by their greater rounding their more distant derivation. From the conglomerate to the slate there is a rapid but not abrupt transition, the slate containing less and less of the schist detritus as it is followed to the north and being more and more comcomposed of its usual fragmental quartz and feldspar.

It should be said here that when we look in general at the fragmental rocks of the iron-bearing series of the region we can say not only that their materials are theoretically derivable from the rocks of the gneissic series to the south, but even that there is a change in their composition as one passes along the strike of the several rock belts, which may be correlated with the change in character of the rocks which are exposed in the gneissic region to the south.

Any one of the arguments thus presented would alone be sufficient to render exceedingly probable the existence of this unconformity. Taken together they seem to constitute a complete demonstration.

North of the narrow belt of country occupied by the iron-bearing series in this region and all the way to the shores of Lake Superior, the rocks of the Keweenaw series are at surface, with the exception of a belt of country in the vicinity of Chequamagon Bay, which the Potsdam sandstone underlies, and of a small area in the vicinity of Presqu'Isle River, which is also occupied by the same formation. This sandstone, as already indicated, lies horizontally upon the upturned beds of the iron-bearing series and of the Keweenaw series. The nature and general structural characters of the Keweenawan

rocks I have somewhat fully described elsewhere. Here it is merely necessary to say that the group consists of a great series of eruptive flows, alternating with which are beds of detrital material, and following which is an immense thickness of sandstone. In the vicinity of the iron-bearing series these layers stand at high angles and present in strike and dip a general conformity with the layers of the iron series itself; but a closer inspection renders it evident that the upper surface of the iron-bearing series has suffered a deep erosion previous to the spreading upon it of the great flows of which the lower portion of the Keweenaw series is composed. This is brought out very strikingly by the accompanying map (see Pl. XLIII), which indicates also that, although the iron series is in one sense unfolded, it nevertheless underwent a certain sort of corrugation prior to the piling upon it of the great Keweenaw series, its beds having been gently bowed upward along certain lines whose direction was transverse to the present courses across the country followed by the outcrops of these beds.

CASES IN WHICH THE OVERLYING STRATA ARE FOLDED.

If, instead of being simply inclined by a depression in one part of the ancient land surface upon which they lie, the strata above an unconformity are pressed together so as to take on a folded condition, still greater difficulties in the recognition of the unconformity may arise. If the bowing is but slight, the case may be but little different from that last considered. But if the folding has been close, so as to produce high inclinations, rapid returns and even overturns of the strata of the upper formation—in which folding of course the underlying formation itself must have taken part—and if the subsequent denudation has been deep, we are presented with the greatest possible obstacles in the way of working out the true structural relation between the two formations. Each may have acquired from the intense pressure accompanying the folding a schistose structure having a general uniform direction, and the laminations of both series will appear to have a generally uniform dip and strike.

Such a condition is well illustrated by the cross-section of the Menominee region of Michigan and Wisconsin given on a subsequent page (see Fig. 95). The iron-bearing series there shown accumulated in an eroded basin among strata already deeply folded. A subsequent folding process setting in with considerable force, the once horizontal strata were now bent into angulated folds and had developed in them more or less of a schistose structure, after which denudation produced the present surface. The discordance between the two formations is evident enough still in the diagram, but as seen upon the surface of the country (which, in such a region, is essentially all we are able to study) the relation is by no means so plain. In

some cases we must often remain at fault, but in others, again, the true relations may gradually be worked out. Discordances in strike and dip at the contact of the two formations are, of course, not of frequent occurrence in such extreme cases, and perhaps the lithological contrast between the two formations may not at first sight be very striking. But such contacts as there may be, if accompanied also by the presence of basal conglomerates in the upper series, will often enable us gradually to work out the true structure.

EXAMPLES.

The Laurentian-Huronian unconformity of the north shore of Lake Huron.—The relation of the original or type Huronian of this region to the horizontal Cambrian and Silurian formations has already been referred to and illustrated by a section copied from Logan (see Fig. 85). The same section shows very plainly what Logan's views were as to the relations between the Huronian and the underlying gneisses in the same region. It has been denied[1] that Logan believed in such an unconformity, but this section and the others accompanying it in the atlas to the Geology of Canada show that he must have done so. These sections, I am told, were reproduced from drawings by Logan's own hand. The same belief is indicated by his description in the Geology of Canada[2] of the occurrences on Lake Temiscamingue, where the Laurentian gneiss is said to be followed by a slate conglomerate "holding pebbles and bowlders, sometimes a foot in diameter, of the subjacent gneiss, from which they appear to be principally derived." On Logan's view as to the metamorphic origin of gneiss, plainly the occurrence of such conglomerates at the base of the Huronian could only be explained by an unconformable break. Statements in less well known publications by Logan[3] have placed

[1] A. R. C. Selwyn, in a paper On the geology of Lake Superior, Proc. Trans. Royal Soc. Canada, vol. 1, sec. 4, p. 119.

[2] Geol. Survey Canada, Rept. Progress, 1863, p. 50.

[3] In a paper by Logan On the division of the Azoic rocks of Canada into Huronian and Laurentian, Proc. Am. Assoc. Adv. Sci., Montreal meeting, 1857, part 2, p. 45, the following paragraph occurs:

"In the same report is mentioned, among the Azoic rocks, a formation occurring on Lake Temiscaming and consisting of siliceous slates and slate conglomerates, overlaid by pale sea-green or slightly greenish-white sandstone, with quartzose conglomerates. The slate conglomerates are described as holding pebbles and bowlders (sometimes a foot in diameter) derived from the subjacent gneiss, the bowlders displaying red feldspar, translucent quartz, green hornblende, and black mica, arranged in parallel layers, which present directions according with the attitude in which the bowlders were accidently inclosed. From this it is evident that the slate-conglomerate was not deposited until the subjacent formation had been converted into gneiss, and very probably greatly disturbed, for, while the dip of the gneiss, up to the immediate vicinity of the slate-conglomerate, was usually at high angles, that of the latter did not exceed nine degrees, and the sandstone above it was nearly horizontal."

Again, in the Quart. Jour. Geol. Soc. London, vol. 21, 1865, p. 46, in a paper On the occurrence of organic remains in the Laurentian rocks of Canada, he says: "The

the matter entirely beyond doubt, showing certainly his full belief in such an unconformity.

So far as concerns that portion of the original Huronian of which I have been able to gain a personal knowledge, the principal proofs of an unconformity lie in the abundant occurrence in the upper series of fragments of the gneiss, granite, and crystalline schists of the lower and in the relatively slightly altered and gently bowed condition of the entire Huronian series as compared with the intense changes and close crumpling which the gneissic formation must have undergone. Particularly striking is the basal conglomerate to be seen about two miles to the east of Thessalon River, where the arenaceous quartzite forming the base of the series may be seen, with a gentle westward dip, resting against a gneissic rock, enormous fragments of which it carries, of all sizes and all degrees of rolling. As one passes away from the immediate contact, these fragments become smaller and tend to arrange themselves in regular zones, between which are bands of a less pebbly and more sandy nature. Where the pebbles are plentiful and for some distance from the contact, the sand itself is largely composed of a fine detritus directly derived from the gneiss. There are also included enormous fragments of various highly altered greenstones and schistose rocks which occur in place within the gneissic formation. The illustrations of this occurrence here given are reproductions of photographs (Plates XLIV to XLVII).

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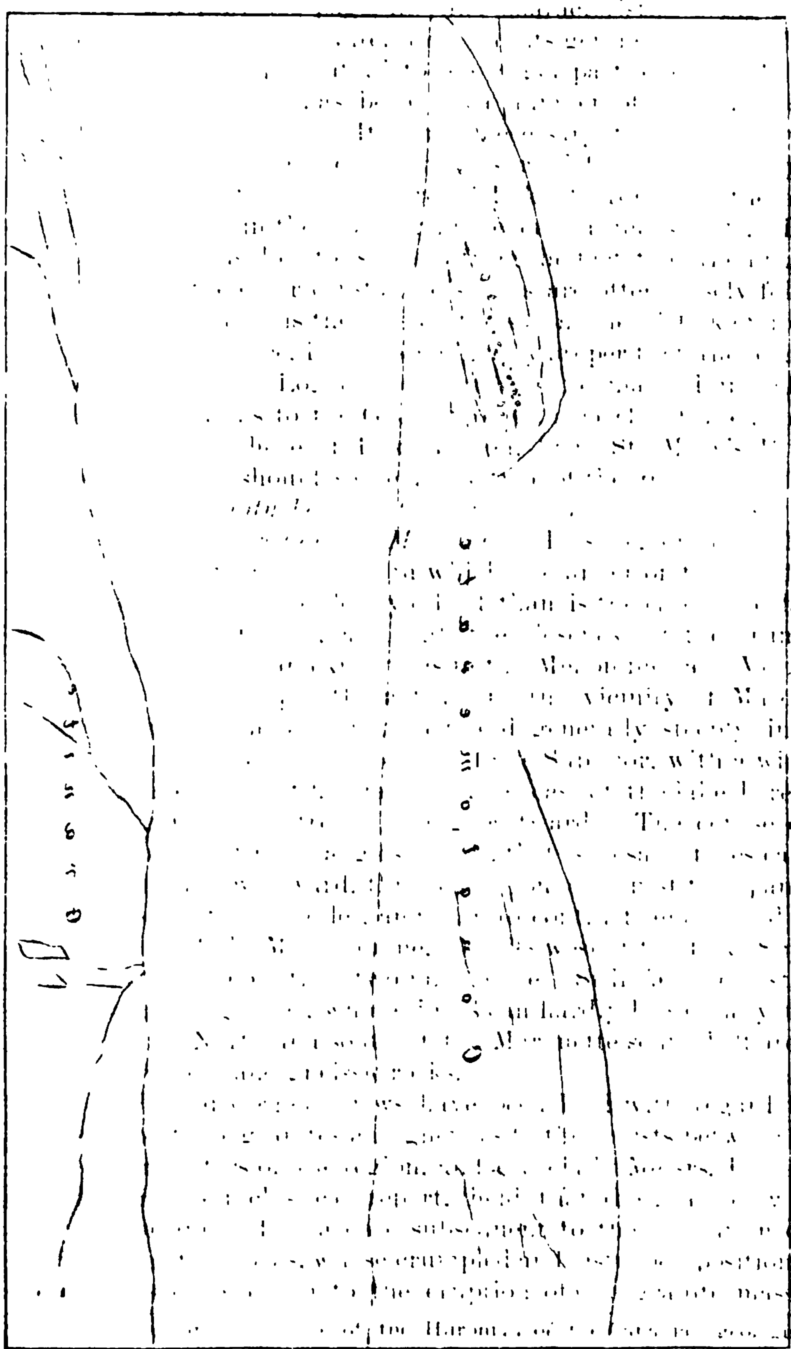
horizontal strata, which form the base of the Lower Silurian in western Canada, rest upon the upturned edges of the Huronian series, which in its turn unconformably overlies the Lower Laurentian. The Huronian is believed to be more recent than the Upper Laurentian series, although the two formations have never yet been seen in contact."

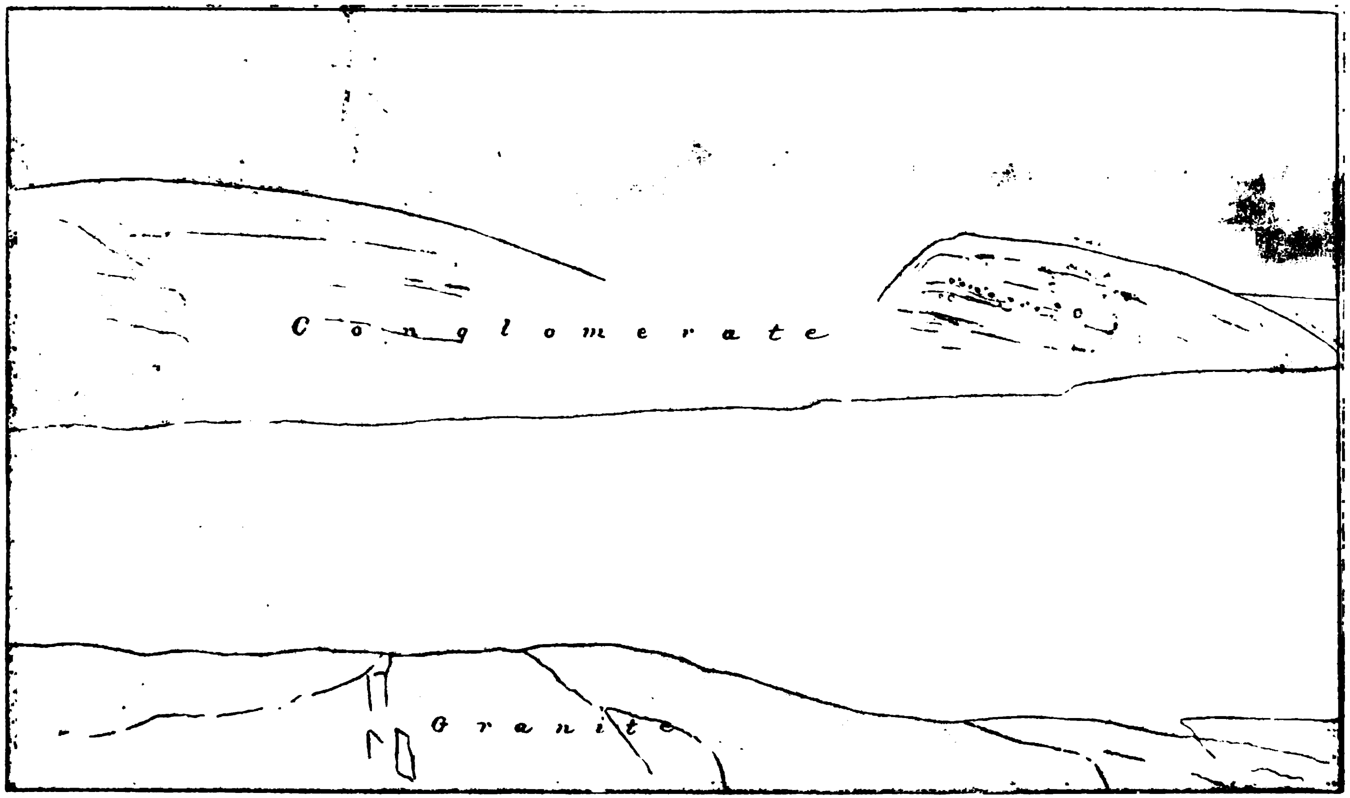
Some of the confusion with regard to this matter has proceeded from a singular statement made by Logan in the Geology of Canada, p. 55, which runs as follows: "The gneiss extends to the vicinity of a small stream about a mile and a half above Les Grandes Sables, and what is supposed to be the lowest Huronian mass of that part occurs about half a mile above the stream. It consists of a gray quartzite which abuts against one mass of gneiss and runs under another, and appears to be much broken by and entangled among the intrusive rock; but judging from a transverse measure in one part its thickness would not be far from five hundred feet."

It has always seemed to me in reading this statement that some printer's error must have crept into the text. We may conceive of Logan's stating that the quartzites abut against one mass of gneiss and run under another; but how he should speak of gneiss as an intrusive rock I certainly cannot understand. However this may be, having been on the ground with Logan's descriptions in my hand, I am able to say that this place shows the quartzite dipping gently to the westward in distinctly unconformable position with regard to the gneiss, fragments and masses of which occur in the quartzite in the greatest profusion. Though I saw no such appearance as would justify the statement that the quartzite lies under the gneiss I can conceive that this misconception might have arisen from the occurrence within the quartzite of large gneiss masses or from the projection of irregular protuberances into the quartzite from the surface of the gneiss. Certainly the place furnishes the handsomest example of a basal conglomerate that I have ever met with.

BASAL CONGLOMERATE IN THE SIOUX QUARTZITE SERIES NEAR NEW ULM, MINN.

VIEW AT THE JUNCTION OF THE HURONIAN AND LAURENTIAN, NORTH SHORE OF LAKE HURON.





VIEW [illegible] JUNCTION OF THE HUR[illegible]AN S[illegible] ON NORTH SHORE OF LAKE H[illegible]N

The general nature of the Huronian of Lake Huron has been indicated on a previous page, its chief characteristics being its fragmental nature, its slight alteration, and its gentle folding. This description will not apply at all to the larger part of the rocks which the Canadian survey has been for a number of years and still is mapping as Huronian. It is not necessary to inquire now just when and how the term came to be spread from the plainly fragmental series of the north shore of Lake Huron over these other rocks, which are in the main genuine crystalline schists. Part of the confusion has doubtless arisen from the fact that the fragmental series and the older crystalline schists are often closely folded ir with one another, as is the case on the south side of Lake Superior. However this may be, it seems eminently proper that the formation of that area which Logan and Murray have mapped in detail on Pl. III of the atlas to the Geology of Canada (1863), i. e., the area along the north shore of Lake Huron, from St. Mary's River to Thessalon River, should serve as the type of the group.

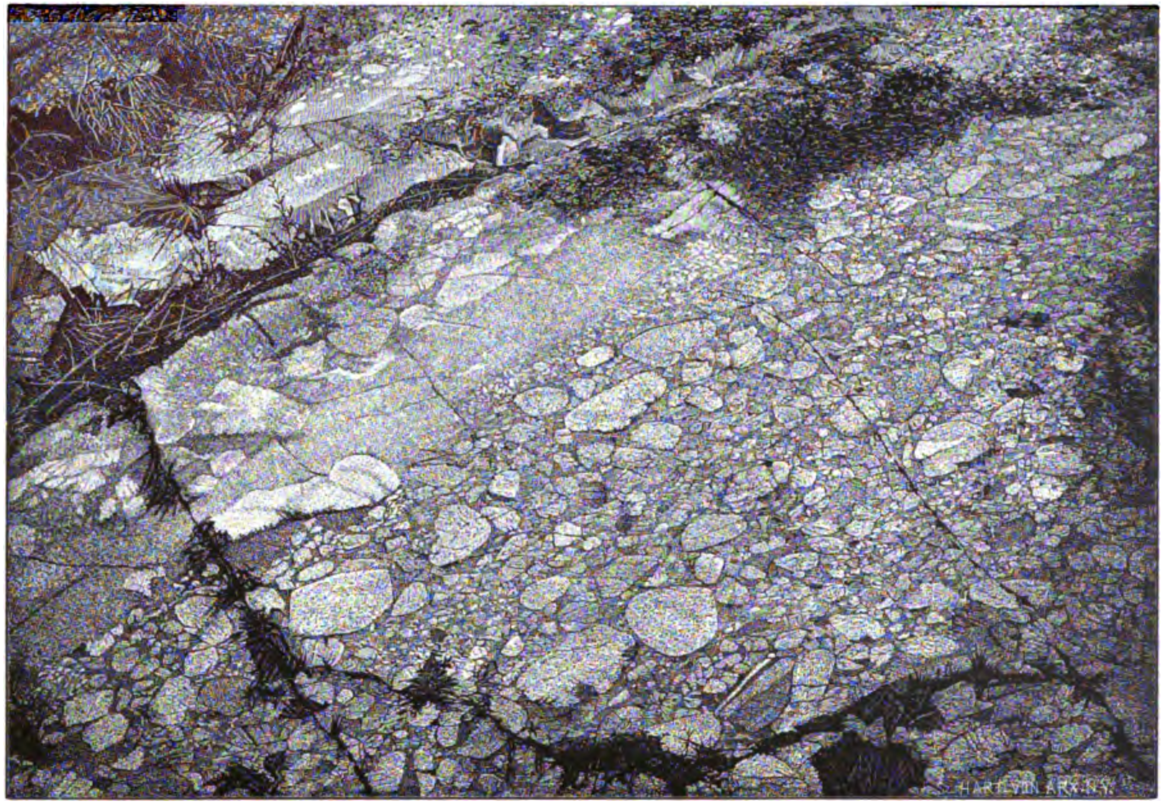
The unconformity between the iron-bearing and gneissic series in the Marquette region of Michigan.—This region furnishes an instance of an unconformity in which the upper of the two formations concerned is more closely folded than is the case with the Huronian on Lake Huron, although the closeness of the crumpling does not reach such an extreme as in the Menominee and Vermilion Lake regions, subsequently noted. In the vicinity of Marquette, Mich., a belt of much crumpled and generally steeply inclined schistose rocks reaches the shore of Lake Superior, with a width on the shore-line of about five miles. The coast of the lake here has a nearly due northerly trend, facing eastward. The course of the schistose belt is at right angles to this, that is to say, it lies east and west. Followed westward, this belt is found at first to expand to a width of some twelve miles, and then to contract again until at the eastern end of Lake Michigamme, 30 miles west of the Lake Superior coast, it is little more than two miles wide. Still farther west it expands over a large area, whose limits can hardly be said as yet to be determined. North and south of the Marquette schist belt are large areas of granitic and gneissic rocks.

Two widely divergent views have been held with regard to the relations of these granites and gneisses to the schists between them. The earlier writers on the region, and especially Messrs. Foster and Whitney in their classical report, held that the granites were of eruptive origin and of a date subsequent to the formation of the various schistose rocks, whose crumpled and disturbed positions they were disposed to assign to the eruption of the granite masses on

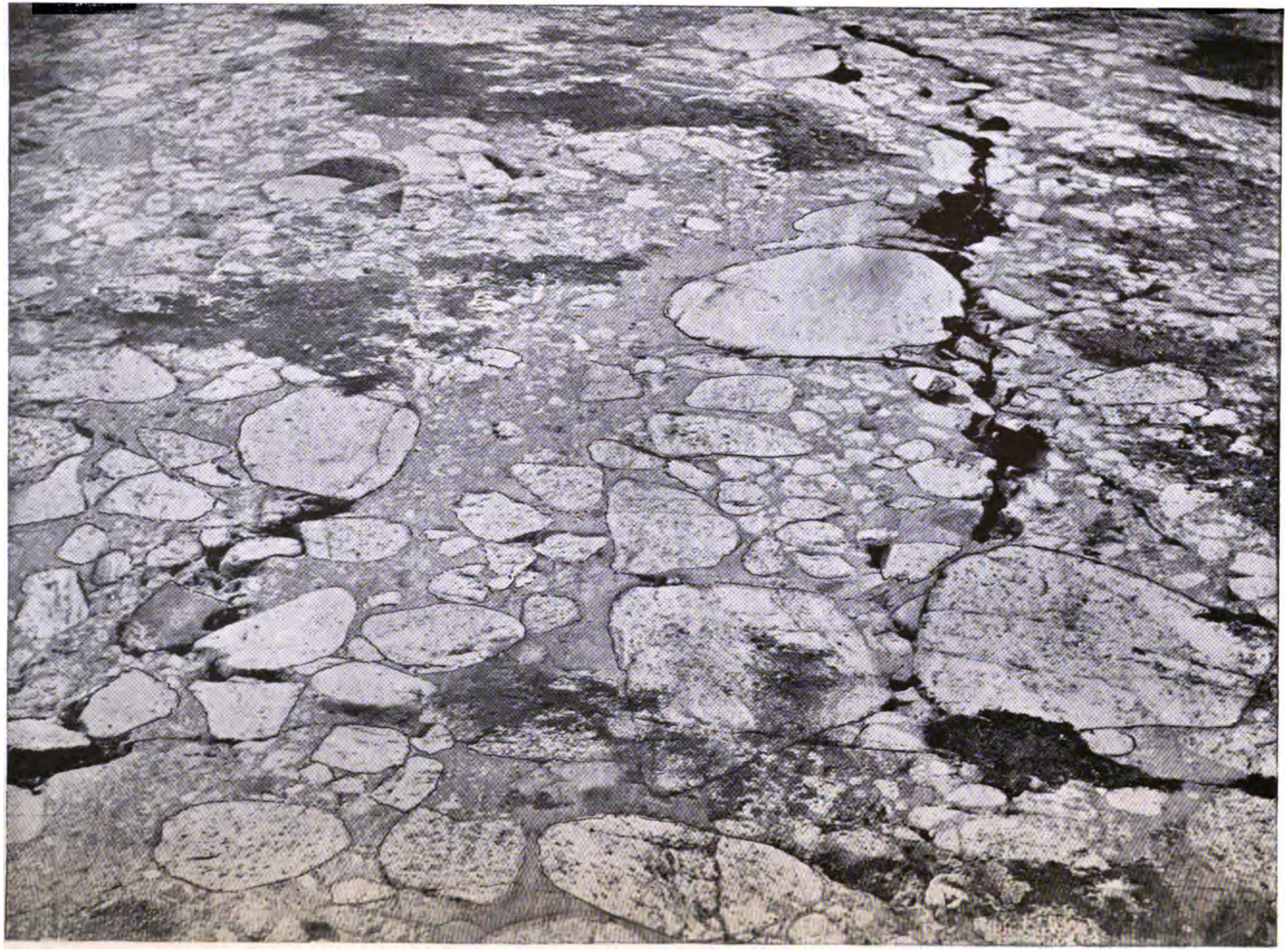
[1] That the composite nature of the Huronian of the Canadian geologists has struck others than the writer will be seen from Bonney's remarks in the Quarterly Journal of the Geological Society of London for May, 1886, p. 83.

either side of the trough. Later, on account of the arguments of Kimball, Murray, Brooks, and others, the view came to be generally held that the granitic and gneissic rocks represented the ancient Laurentian basement, upon which the schistose or Huronian rocks were distributed unconformably; that, the whole region having been subsequently affected by lateral pressure, the sedimentary rocks were pushed into folds; and that the granitic rocks on either side were brought to the surface by denudation. Recently the older view of Foster and Whitney has been advocated by Mr. M. E. Wadsworth and Dr. C. Rominger, both supporting the view by appeal to intrusions of the schistose rocks by granite. It is true, of course, that these granitic intrusions might be in part quite independent of, and of later date than, the great granitic masses, but Dr. Rominger has shown that intrusions of the schists along their contacts with the granite are so plentiful in certain parts of the region that it seems necessary to conclude that such invaded schists are older than the granitic masses themselves. On the other hand, certain of the contacts of the schists with the granite are found to present admirable examples of basal conglomerates, the granitic and gneissic rocks having evidently been beaten upon and broken down by the sea in which such schists were laid down.

These entirely contradictory appearances, however, find a very simple explanation in the view that the schistose rocks themselves are in fact made up of two entirely distinct series: an older series of very intensely altered and crumpled schists, in the main of a greenish color, which are invaded intricately by the granite at their contacts with it, and a newer, feebly altered, slaty series whose contacts with the granites and the schists of the older basement are such as to render the intervening structural break very evident. The contrast between these two sets of schists as to degree of alteration and the penetration of the one set by the granite while the others show no such penetration were partly realized by Dr. Rominger, as indicated in his reports on the northern peninsula of Michigan, in which, however, he still continues to regard the granite masses as newer than all the schistose and slaty rocks of the region, the high degree of alteration of the schists penetrated by them as compared with the smaller degree of alteration of the remaining schists being explained by the greater proximity of the one set to the granite. In the same report Dr. Rominger shows, however, that the relatively unaltered slates often come directly in contact with the granite, in which case they present a peculiar appearance, suggesting to him an alteration by contact with the eruptive masses. The peculiar granitoid quartzites, however, which he takes to have been produced by the heat of the granite, are beyond question merely detrital derivatives from the granite and often run into coarse bowlder conglomer-



CONGLOMERATE OF THE ISLAND SHOWN IN PL. XLV.



ANOTHER VIEW OF THE CONGLOMERATE OF THE ISLAND SHOWN IN PL. XLV.

ates, as Dr. Rominger now realizes and states. However, neither he nor any other writer on this region seems to have realized that the clew to the geology of the region lies in the separation of the schists and slates into two entirely distinct and discordant series, which are plainly the same as those of the Penokee country of northern Wisconsin and as those of the region north of Lake Superior, both of which regions have already been cited as furnishing instances of unconformities where the upper series is only highly inclined without folding. They are also the same as the two discordant formations of the north shore of Lake Huron. These are the *upper*, relatively feebly altered, iron-bearing, slaty and quartzitic group, or *Huronian*, and the *lower*, greatly altered, gneiss, granite, and green-schist group, or *Laurentian*.

This truth thoroughly appreciated, most of the proofs cited to establish the existence of an unconformity in the Penokee region are found to present themselves here also. Not only are the two formations of the Marquette region manifestly identical with those of the Penokee region, with which they are, moreover, probably directly continuous, and therefore inferentially discordant with one another, but such a discordance for the Marquette region may be proved on the ground by the discordant positions of the schists of the two series when in contact or near proximity, by the large development of basal conglomerates where the two formations come together, by the indifference in position of the belts of the upper series to those of the lower, by the striking contrast in amounts of alteration of the upper and lower schists, and by the totally dissimilar relations of the two sets of schistose rocks to the plainly eruptive granite masses.

That all of the rocks of the Marquette belt should have been counted as making up one formation is not at all to be wondered at. The infolding of the two sets of schists and slates has produced, of course, a tendency to a general parallelism in their bearings; but, to render the case still more difficult of comprehension, the denudation that has so deeply invaded the region has brought to light, within the area occupied by the newer slates, patches of the underlying older schistose basement, which patches, completely surrounded or bordered closely on either side by the newer slaty rocks, it has seemed necessary to regard as parts of the same formation. The matter has been yet further complicated by a resemblance, partly very close and partly only macroscopic, or even imaginary, between certain of the older schists, which are in part intensely altered and squeezed basic eruptives, and certain interbedded basic eruptives of the upper formation. Such a difficulty as this could only be put out of the way by the use of microscopical methods of study, and these, of course, were unknown to all of the earlier geologists and were insufficiently used by the later writers on the region.

Herewith I give two generalized north and south cross-sections of the Marquette schistose belt, one in the immediate vicinity of the

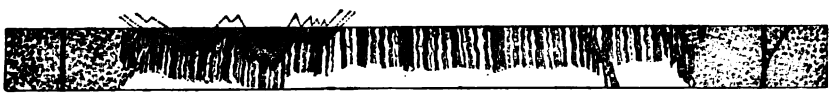
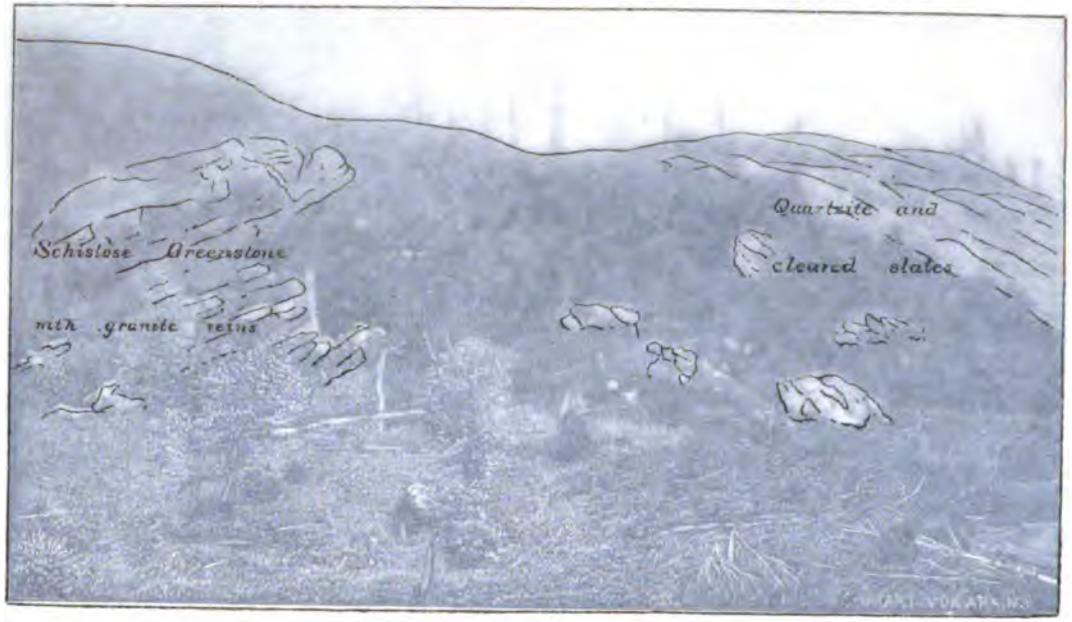


FIG. 93. Generalized north and south section near Marquette, Mich., looking west. Scale, 1.65 miles to the inch. A belt of greenish, highly compressed and altered schists is bounded by granite masses which are of eruptive origin and penetrate the schists intricately at their contacts with them. Unconformably overlying these rocks are crumpled and relatively little altered layers of the iron-bearing series, including here sericitic and novaculitic slates, quartzite, and siliceous and slaty limestone. The first two of these are wholly, the third in part, of fragmental origin, and include at their contacts with the older granites and schists numerous fragments of the latter rocks.

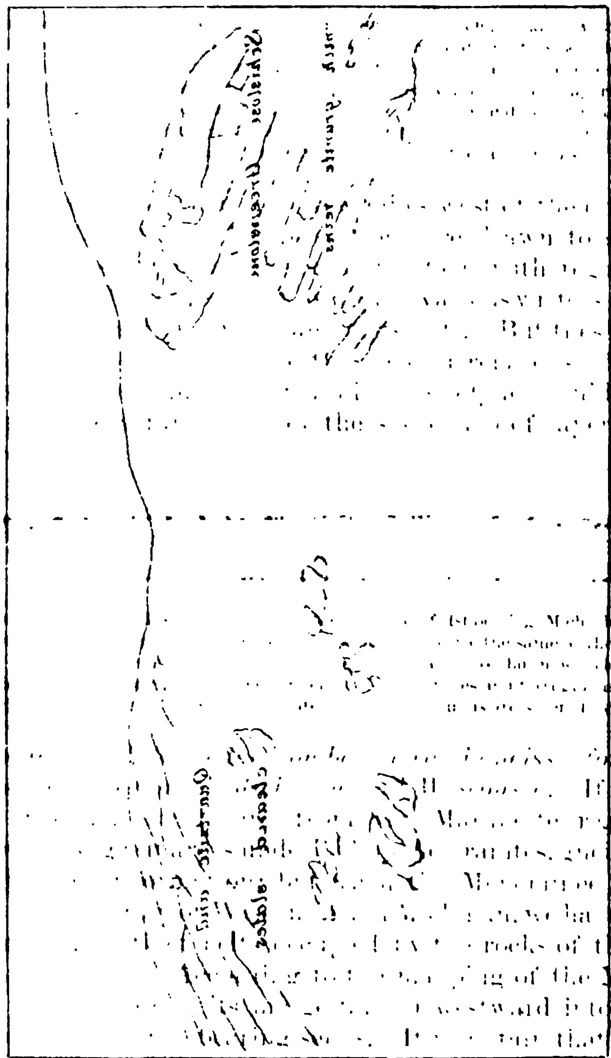
city of Marquette, the other some few miles west of the city of Ishpeming (Figs. 93 and 94). These sections are drawn to scale and are based upon a study of all the available facts with regard to the region, including those presented by all the various writers and such as have been obtained by myself and assistants. But these sections are designed now only to indicate the general relations of the two formations of the region. No such minute study as would warrant a final mapping or arrangement of the succession of layers has yet been made.

FIG. 94. Generalized north and south section in the vicinity of Ishpeming, Mich., looking west. Scale, 2.6 miles to the inch. The vertically placed schists and granite are the same as those in Fig. 93. Unconformably overlying these is the iron-bearing series, as in that figure, but now including higher layers, viz, in the southern trough an alternating series of greenstones and ferruginous schists, and in the northern ferruginous schists succeeded by slates. The two troughs are severed by denudation.

The unconformity between the iron-bearing and gneissic formations in the Menominee region of Michigan and Wisconsin.—If we proceed in a direction southward from the Marquette region (Pl. XLVIII) we cross great areas underlaid by the granites, gneisses, and schists of the older formation; but when the Menominee River is reached, at the boundary of Wisconsin and Michigan, we have crossed also at least four distinct belts occupied by the rocks of the newer or iron-bearing series. According to the mapping of the Michigan geologists, these several belts merge farther westward into a single extended area of the iron-bearing series. It is certain that this formation has a wide spread in that direction, but it is equally certain that it is not so widespread as it is represented on their maps, since they have included areas which can now be referred without question to the older formation. Just what the relative extents of the two formations in this direction are remains to be shown by further exploration. Of the several belts indicated as crossed by a line run-



VIEW TWO MILES SOUTH OF MARQUETTE, MICHIGAN.



VIEW TWO MILES SOUTH OF MARQUETTE, MICHIGAN.

ning south from the Marquette belt to the Menominee River, that one skirting the Menominee River on its northern or Michigan side and running thence west and north into Wisconsin is the most extensive. The accompanying Fig. 95 is designed to represent the general relations of the two formations and the nature of the folding of the strata in this region. As in the case of the sections of the Marquette region, this one also has been drawn to scale after a careful study of all facts hitherto published and of those gathered by myself and assistants. The two formations concerned are manifestly identical with those of the Marquette region. We have here again to do with an upper, relatively little altered, iron-bearing series and a lower, deeply altered series of gneiss and schists; with immense areas of intrusive granite. The principal point of difference between the two regions lies in the much closer folding that the Menominee rocks have received. Had the section been made farther west a larger thickness of the Huronian strata would have been shown and other folds would present themselves. All the arguments that applied in the Marquette region in favor of the existence of a discordance between the two formations apply here again. The basal conglomerates of this series are particularly finely developed and may be seen on a grand scale at the contact of the basal quartzite with the granite at the falls of the Sturgeon River.

FIG. 95. Generalized cross-section of the eastern part of the Menominee iron district in the vicinity of Quinnesec, Mich. Scale, 2.3 miles to the inch. The older schist series, with its intrusive granite, and the unconformably overlying iron-bearing series, composed of a succession of sericitic slate, quartzite, ferruginous schist, and argillaceous slate layers, are folded in together in such a manner as to present an appearance of conformity at surface with prevailing high dips to the south.

The several belts that intervene between the one just described and that of the Marquette region are much narrower, but nevertheless seem to contain as great a thickness of the iron-bearing formation as is usual in this region. In the case of the Felch Mountain belt, which does not exceed a mile in width, all of the strata dip at a high angle to the northward, and in crossing the belt from the south to the north, after passing the middle, one passes over a repetition of the layers crossed farther south, but in an inverted order, and we have evidently to do with a case of a syncline with the sides folded closely together. Fig. 96 shows in a general way the relation between the several belts from the Marquette region to the Menominee River.

The unconformity among the schistose rocks of the Vermilion Lake region.—The schistose rocks which have already been alluded to as

having so great a development in northeastern Minnesota, north of the northern limit of the Animiké beds, form a belt which extends from Vermilion Lake in an easterly and north of east direction to the national boundary line, in the vicinity of Knife and Saganaga Lakes, a distance of some sixty miles. (See map, Pl. XLI.) To the west of Vermilion Lake this belt has been traced for some miles, but is soon lost underneath the heavy accumulations of glacial drift of that region. To the north it is bounded everywhere by granitic and gneissic rocks, the granites penetrating the schists along the margin of the belt, and for some distance inward also, in a most intricate manner. A similar area of granite and gneiss bounds the schistose belt on the south over much of the distance, and here also are seen again the intricate intersections of the schistose rocks by the granite. After reaching a point some thirty miles east of Vermilion Lake, however, the great flat-lying mass of gabbro which lies at the base of the Keweenaw series of that region overlaps and conceals this granite, the overlap extending to the schistose belt itself. Another granite area lies directly athwart the course of the schists in the vicinity of Saganaga Lake, although a portion of the schist belt apparently continues farther to the northeast into Canada along the northwestern side of this granite.

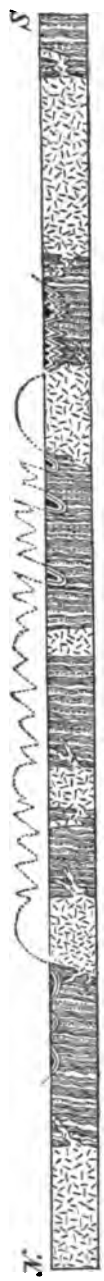
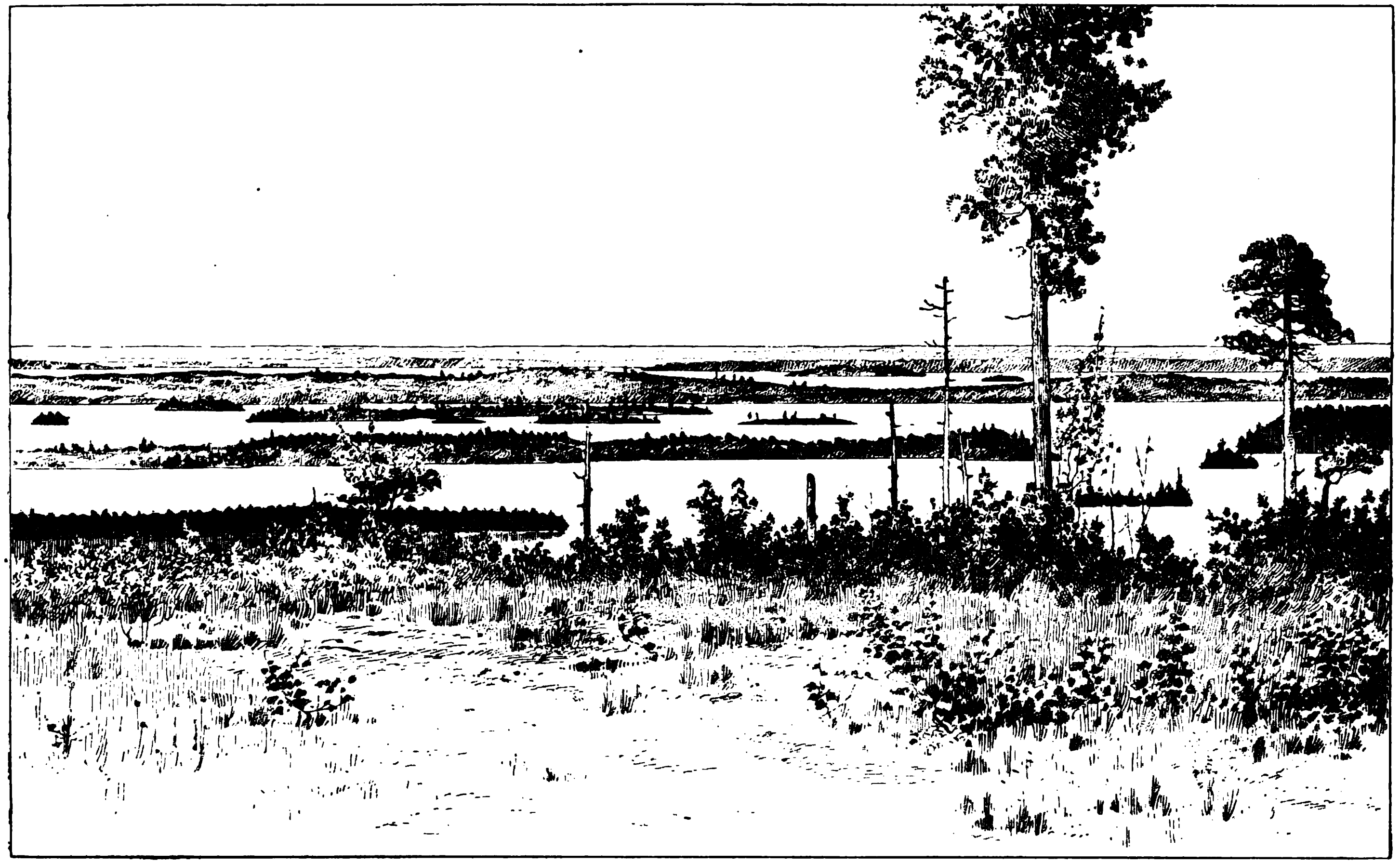


FIG. 96. Section north and south through the Marquette and Menominee iron districts of Michigan and Wisconsin, looking east. Scale, 18 miles to the inch. The older series of schists, with masses of eruptive granite, make up most of the section. Five belts of the iron-bearing group are crossed by the section, the northernmost being the Marquette belt, the southernmost that of the Menominee River, while the narrow troughs midway the section are the belts of Felch Mountain and vicinity. The iron-bearing rocks were once continuous over the whole area, but have been removed by denudation from the intervening spaces.

Folding and the production of schistose structure by lateral pressure seem to have been pushed to the very last extreme among the rocks of this schist belt, the dips within which are generally nearly vertical, although here and there among some of the fragmental rocks of the belt close crumplings may be traced, with their sharp anticlinal and synclinal bends. The secondary schistose structure, with its accompanying metasomatic changes, has been developed to the highest degree among the rocks of eruptive as well as among those of sedimentary origin. The common structural directions of all the rocks of the belt, as to both strike and dip, and the generally prevailing schistose structure suggest at first most certainly the conclusion that all of the schists of the belt are part of one formation, or, if of two formations, that the distinction between the two is no longer recognizable.



GENERAL VIEW OF VERMILION LAKE.

A closer study, however, serves to render such a conclusion less evident and shows that we have among the rocks of the belt two types, in one of which the crystalline structure is complete and in which there is little or none of an original fragmental structure, while in the other the fragmental texture is still distinct and the alteration has progressed to a smaller degree. Associated with the latter schistose rocks, are found great developments of jaspery and cherty, ferruginous schists, whose identity as to nature and origin with the ferruginous schists of the iron-bearing formation of the south shore of Lake Superior and of the Animiké formation of the north shore is complete. This identity, taken together with the close similarity of some of the fragmental rocks associated with the schists of the Vermilion Lake band to the fragmental rocks of the Animiké and of the south shore iron-bearing formation, and with the additional similarity that obtains between the remaining schists of the Vermilion Lake band and those of the older or gneissic formation of the south shore of Lake Superior, suggests to us that we have here again to do with a separation into an older and a newer schistose formation. The suggestion is de pened into conviction when we further consider the fact that the supposed older one of the two groups of schists in the Vermilion Lake belt is intricately penetrated by the granites of the great areas north and south of the belt, while the same granites, where they come in contact with the supposed newer schists, have yielded to them a profusion of fragmental material, among which material are many fragments derived from the supposed older schists themselves. The conclusion is, then, that the conditions obtaining in the Vermilion Lake belt are analogous to those which present themselves in the Menominee region, already briefly described, with the difference that the folding and schistose structure due to lateral pressure have been pushed to a far greater extreme in the former region (Pl. XLIX).

RÉSUMÉ.

The examples thus presented of unconformities in which the upper formation is displaced from its original horizontal position furnish us with a graded series. The Animiké rocks lie upon the older formation with but a slight inclination, while the Penokee iron-bearing series, though still unfolded, lies with a steep dip against a wall of the older formation. Next in the series comes the case of the Huronian-Laurentian unconformity on the north shore of Lake Huron, where the upper formation is gently bowed, but is without true schistose structure. In the case of the unconformity of the Marquette region, the upper formation is crumpled, even having the folds at times overturned, with frequent developments of slaty cleavage, but still having the folds in the main open and presenting a true schistose structure only rarely. In all of these cases, least distinctly of course in the last case, the discordance of the two formations concerned is to be

made out in part from the visibly discordant positions of the rocks of the two series. But when we proceed to the next case on the list, that of the Menominee region, such discordances are no longer to be made out with any distinctness, the close folding having brought the stratiform members of both groups to too great a uniformity of inclination. Finally, in the Vermilion Lake region, the extreme pressure to which they have been subjected has brought about not only a general community of inclination between the rocks of the two groups, but has developed in the lower group and among the eruptives of the upper group so complete a schistose structure as to render the separation of the two series often exceedingly difficult. Nevertheless, that the two groups are there actually represented the general argument above presented seems to me clearly to demonstrate, while such a state of affairs as there obtains is certainly no theoretical impossibility, on the hypothesis that these schists include two entirely distinct series of rocks.

THE USE OF UNCONFORMITIES IN CLASSIFICATION.

The use of unconformities in defining the grander groups of strata.—Returning to our problem as originally stated we have next to consider how far unconformities may be made use of in defining the grander groups of strata in a region in which the succession of these strata has been determined. Further argument than that already given in discussing the nature and kinds of unconformity is hardly necessary to show that genuine unconformities, indicative of great lapses of time between the periods in which the strata on either side of the break in each case were respectively made, are of prime value and importance in determining the limits of the grander groups of the geological formations, whatever use we may make of paleontological and lithological characters in determing subordinate divisions. Such structures as the greater ones of the true unconformities, above considered, indicate lapses of time great enough to cover extended periods of mountain-making, always a slow process, and also great periods of denudation or exposure to the atmospheric agencies. It is hardly possible for us to compare such time gaps with the time necessary for the formation of definite thicknesses of strata, but the thicknesses of strata corresponding to such breaks must surely always be very great.

If we take, for instance, the gap indicated by the relations of the Potsdam sandstone to the ancient gneissic formation of the Northwest, as above illustrated by a number of examples, we find that it was long enough to cover not merely one period of rock alteration, orographic movement, and land surface exposure, but three such periods, between which were times long enough for the accumulation of thicknesses of strata aggregating over sixty thousand feet — a thickness exceeding that of the entire Paleozoic series in its greatest

development in the Appalachian region. It is true that a portion of this sixty thousand feet is made up of volcanic materials, chiefly lava flows. The accumulation of such materials may, it is true, have been more rapid than is the case with ordinary fragmental deposits; but the accumulation of such a mass of eruptive material must have occupied at least a considerable lapse of time; while more than one-half of the sixty thousand feet, or an amount approximating the maximum Paleozoic accumulations in the Appalachian region, is made up of genuine detrital deposits. When we consider that, in addition to the time necessary for the accumulation of this mass of sediment, there intervened between the Potsdam and the gneisses three periods, of rock alteration, mountain making, and complete mountain removal, it becomes plain that the time gap indicated by this unconformity must have exceeded the entire Paleozoic era. More probably, indeed, it equaled all later geological time. Each one of the three unconformities mentioned must, of course, have required a shorter period than this greater gap, but in each case the relations of the several formations are such as to indicate periods of time only comparable to the periods necessary for the accumulation of one of the great geological groups.

The use of unconformities in correlating the formations of a single geological basin.—We have next to consider the second element in the problem announced at the beginning of the paper, viz, the mutual correlation of the several successions of strata occurring in different portions of a single geological basin. For one reason or another the different districts in which these successions occur cannot be connected. Some of the formations may be wanting or later accumulations may conceal them, or, if they are technically the surface rocks throughout the interval, the drift covering may be so heavy that they cannot be studied successfully. In such a case as this, of which we could have no better instances than are found within that northwestern portion of the United States to which reference has so often been made, the unconformities prove of the highest importance in establishing the correlations. If we have a certain succession in one district, with a certain number of unconformable breaks, and a similar succession in another district, say fifty miles or a hundred miles away, with the same unconformable breaks, we can correlate the two series without hesitation, parallelizing with one another not only the several series concerned, but also the unconformities.

Such a use of unconformities can be much better appreciated from illustration. The following tabulation shows the general succession of formations in each one of the districts named, all of these districts lying within that great northwestern region of Cambrian and Pre-Cambrian rocks which, so far as the United States is concerned, extends westerly from the northern end of Lake Huron to southeastern Dakota and northward from central Wisconsin to the north shore of Lake Superior.

Correlation of the rock groups and un

Groups.	North shore of Lake Huron, Canada.	Keweenaw Point, Michigan.	Marquette region, Michigan.	Menominee River region, northeastern Wisconsin and Michigan.	Penokee-Gogebic region, northern Wisconsin and Michigan.
CAMBRIAN.	Calciferous sandstone.		Lower magnesian limestone.	Lower magnesian limestone.	
	Potsdam sandstone.	Lake Superior sandstone.	Potsdam sandstone.	Potsdam sandstone.	Lake Superior sandstone.
Unconformity.		*Unconformity.*			*Unconformity.*
KEWEENAWAN.	*Unconformity.*	Keweenaw series of alternating eruptive and detrital beds, 26,000 feet; the upper and lower limit not in sight.	*Unconformity.*	*Unconformity.*	Keweenaw series of detrital and eruptive rocks, 45,000 feet; lower limit seen, but not the upp r.
Unconformity.					Discordance and erosion interval.
HURONIAN.	*Original or type Huronian:* (Principal kinds of rocks in order of relative abundance.) Quartzite and sandstone. Graywacke and graywacke slate. Conglomerate. Limestone and chert. Greenstones (eruptive). 18,000 feet.		*Iron-bearing series:* Graywacke and clay slates. Quartzite and quartzite-schists. Mica-slate and schist. Limestone. Ferruginous and jaspery schists. Carbonaceous slate. Greenstones (eruptive). 5,000 to 10,000 feet.	*Iron-bearing series:* Quartzite and quartzite-schist. Limestone. Clay slate. Ferruginous and cherty schists. Carbonaceous slate. Mica-schist and slate. 10,000 feet.	*Iron-bearing series:* Graywacke and graywacke slate. Mica-slate and mica-schist. Quartzite and sericitic quartz-schist. Ferruginous and cherty schists. Carbonaceous slates. Limestone. Greenstones (eruptive). 13,000 feet.
Unconformity.	*Unconformity.*		*Unconformity.*	*Unconformity.*	*Unconformity.*
LAURENTIAN.	Gneiss. Granite. Dark-colored schists.		Granite. Gneiss. Green schist. Mica-schist. Hornblende-schist.	Granite. Gneiss. Green schist. Mica-schist. Hornblende-schist.	Granite. Gneiss. Green s hist. Mica-schist. Hornblende-schist.

conformities of the Lake Superior region.

Black River region, central Wisconsin.	Thunder Bay and Pigeon River region, Canada and Minnesota.	St. Louis, St. Croix, and Mississippi Rivers, central and eastern Minnesota.	Vermilion Lake region, Minnesota.	Baraboo region, central Wisconsin.	Southwestern Minnesota and southeastern Dakota.
Lower magnesian limestone.		Lower magnesian limestone.		Lower magnesian limestone.	Lower magnesian limestone.
Potsdam sandstone.		Potsdam sandstone.		Potsdam sandstone.	Potsdam sandstone.
Unconformity.	Keweenaw series, 8,000 feet; upper limit not seen.	Keweenaw series, 40,000 feet; upper limit not seen.	Keweenaw series, 25,000 feet; upper limit not seen.	*Unconformity.*	*Unconformity.*
	Discordance and erosion interval.	*Unconformity.*	*Unconformity.*		
Iron-bearing series: Ferruginous and cherty schists. Sericitic quartz schist. (Thickness unknown; mostly concealed by Potsdam sandstone.)	*Animikè series:* Graywacke and Graywacke slate. Quartzite and sandstone. Ferruginous and cherty schists. Carbonaceous slate. Limestone. Greenstones (eruptive). 5,000 to 10,000 feet.	*St. Louis and Mississippi slate series:* Clay slate. Graywacke slate. Mica-slate. Staurolitic mica-slate. Carbonaceous slate.	*Vermilion Lake iron-bearing series:* Schistose and slaty conglomerate. Basic and acid eruptives (often schistose). Graywacke slates at times carbonaceous. Ferruginous and cherty schists. Quartzite. Many thousand feet thick.	*Baraboo quartzite series:* Ferruginous and cherty schists. Quartzite. Sandstone. Quartzite-schist. Schistose porphyries (eruptive). 20,000 feet.	*Sioux quartzite series:* Quartzite. Sandstone. Undetermined eruptives.
Supposed unconformity.	*Unconformity.*	*Supposed unconformity.*	*Unconformity.*	*Inferred unconformity.*	*Unconformity.*
Granite. Gneiss. Mica-schist.	Granite. Gneiss. Mica-schist. Hornblende-schist. Green schist.	Granite. Gneiss. Mica-schist. Hornblende-schist.	Granite. Gneiss. Green schist. Mica-schist. Hornblende-schist.	Concealed beneath Potsdam sandstone.	Gneiss. Granite. Mica-schist. Hornblende-schist.

This tabulation, with the descriptions already given in connection with the various illustrations of unconformities above cited, will be sufficient to show that the general succession obtaining throughout this region is as follows, in ascending order:

At the base of the succession is a series composed of *gneissic and granitic rocks, with also a large development of schists.* The granite is certainly in the main eruptive. The schists are very largely compressed eruptives, but also in part are of sedimentary origin. This gneissic terrane is always succeeded by a great structural break, it having been subjected to wide-reaching orographic movements, alterations, and denudations before the deposition of the next series.

The following series is a great *quartzite and slate group,* commonly including ferruginous horizons and also limestones and various basic and acid eruptives. This group, while presenting some characters peculiar to each district—depending partly upon original differences in local conditions of deposit, but also, and more particularly, upon the different degrees of alteration to which the rocks have been subjected in different areas—has, nevertheless, a general uniformity of lithological characters, such as to render evident its essential continuity throughout all or most of the different districts.

Next above this iron-bearing group follows a second hiatus, similar in kind and significance to that preceding it. Following this hiatus we have at times the Potsdam sandstone with a very moderate thickness. But in other cases there intervenes between this sandstone and the iron-bearing series the enormous development of detrital and eruptive rocks known as the *Keweenaw series.*

Finally comes the *Potsdam sandstone,* overlying all unconformably.

The least satisfactory portion of the tabulation is that which correlates the quartzite formation of southern Minnesota and southeastern Dakota with the iron-bearing formations of most of the other districts. The gneissic rocks of southern Minnesota are evidently the same as the gneissic formations of the other regions enumerated. Above this gneissic formation in Minnesota follows a hiatus, which is again evidently, in part at least, the equivalent of the gap which is found in the other districts to separate the gneissic from the iron-bearing series. Equally satisfactory is the correlation of the true Potsdam sandstone of Minnesota with that of the remaining districts enumerated, as well as the correlation of the unconformity which, though not actually visible, may, with entire confidence, be asserted to exist between the Potsdam sandstone in Minnesota and the quartzite series of that region with that which in the other districts is found below the Potsdam. In other words, the quartzite series of southern Minnesota lies between the gneissic formation and the Potsdam sandstone of the other regions; that is, so far as position is concerned, it may be the equivalent of the iron-bearing formations of the other districts or of the Keweenaw series or of the gap

between these groups. With the Keweenaw series, as to lithological characters, it has almost nothing in common; with the iron-bearing groups it has in common the quartzitic character, but otherwise has little resemblance to that formation. We are helped a little, however, by a somewhat close resemblance which it bears to the Baraboo quartzite formation of Wisconsin, whose resemblance in turn to the original Huronian of the north shore of Lake Huron is a great deal closer. Again, a great development of a quartzite, the resemblance of which to the quartzites of the Baraboo region and of southwestern Minnesota is so strong that its identity with them may be taken as certain, occurs in Barron and Chippewa Counties, in northwestern Wisconsin. But in this latter region the Keweenaw series itself occurs in full force, and, although the contact of the two is concealed beneath the drift accumulations of the region, their relative geographical positions and inclinations and their striking lithological dissimilarities render it evident that they are entirely distinct formations. By this process of reasoning, making use of the unconformities so far as we can and then of lithological characters, we reach the conclusion that the Minnesota quartzite formation is probably the equivalent of the Huronian of the north shore of Lake Huron, although it has yielded somewhat obscure linguloid impressions which have heretofore never been found below a genuine Cambrian horizon. But the doubt still remains whether this formation may not, in part at least, correspond to the interval which in the Lake Superior region proper lies between the Keweenaw series and the Huronian. The only argument against such a supposition lies in the fact that it also is gently bowed, the presumption being that its disturbance was part of the general orographic movement by which the Huronian of Lake Huron and the equivalent rocks of the other districts were brought into their present positions.

The use of unconformities in establishing general relations.—Having established the general order of succession and the grander groups of the strata for a given geological province, the question which arises next in order is how to correlate these divisions with those of other geological provinces, and more particularly with the established divisions of the general geological column.

It will take but little consideration of the causes which have been at work in the production of such unconformities as have been above cited to make us realize that such breaks as these must be widespread in their influence. Great unconformities, in which the strata below the unconformity have been subjected to folding, mark periods of orographic movements which will, in general, have been extensive somewhat in proportion to the intensity of the folding process. So far as our knowledge extends, the genuine mountain-making movements have never been limited in their scope. We find a moderate instance of the width of influence of such movements in that Post-

Carboniferous upheaval which gave rise to the Appalachian mass. The effects of this movement are recognizable from the seaboard to the western plains and from the Great Lake region to the vicinity of the Gulf of Mexico. The greater part of the force was, of course, spent in the neighborhood of the present mountains themselves; but that its influence extended much farther west is indicated not only by the gentler bowings of the strata, which continue west of the mountains into the Mississippi Valley, but also by the lack of any Post-Carboniferous deposits in all the interior basin east of the Mississippi. Plainly all of this region was raised at that time permanently from beneath the interior sea, which was then shifted to the westward, to be afterwards more and more restricted in area by later mountain-making movements. Should we imagine the Appalachians to be submerged anew and to receive new horizontally placed deposits, the lapse of time indicated by the resulting discordance would fall altogether short of the time gaps indicated by the greater ones of the discordances above cited from the region of the Northwestern States, and would not exceed that indicated by the least of the discordances of that region. The amount of intervening denudation would be less in our supposed case than in the case of any of the northwestern unconformities.

It is well known, indeed, that some of the greater physical breaks in the strata of one continent may have their parallels among the strata of another continent. The interruption between the Paleozoic and the Mesozoic is intercontinental if not world-wide. Equally extensive is the great break between the Mesozoic and the Cenozoic. Each of these physical breaks corresponds to an immense change in life conditions. But, if we may judge from structural relations, from the amount of intervening denudation, and from the rank already attained by the life of the lowest of the fossiliferous Cambrian formations, neither of these great breaks corresponds in length of time interval to the break between the lowest of the distinctly fossiliferous formations and the youngest of those beneath it.

Most of the grand divisions of the geological column are based upon the paleontological characters of the several groups, but among those formations which are especially the subject of this paper, except in the highest, paleontological evidence fails; and in establishing correlations between them for regions more or less distinct from one another, we have to fall back upon mutual structural relations and lithological characters. It has already been argued that lithological characters, in the present state of the science at least, are but an untrustworthy guide in establishing such correlations. It is admitted that there are among the ancient formations some striking lithological correspondences between different regions; but how far these resemblances are significant of chronological correspondences and how far they are merely delusive must remain for the present an open question.

GRANITE VEINS IN MICA SCHIST, ON ISLAND IN BURNTSIDE LAKE.

The great structural breaks furnish, at times at least, a more trustworthy guide. If, for instance, we make a comparison of the succession of Cambrian and Pre-Cambrian strata in the Lake Superior region with the succession revealed in the depths of the Grand Cañon of the Colorado we find some singular correspondences between the structural breaks of the two successions. In each one of these regions the Potsdam sandstone is strongly characterized by its well known fauna. In each region the sandstone traverses the edges of a gently bowed but deeply denuded formation composed of a great thickness of detrital and eruptive materials. Below these formations in each region, and separated from them in each case by one of the strongest of unconformities, is a great quaıtzitic series, while below this series again in the Lake Superior region, and separated from it by still another of the most notable of unconformities, is the great Laurentian gneissic series. That this series also exists in the base of the Grand Cañon we have good reason to believe.

Such a striking similarity in succession as this certainly most strongly suggests the conclusions that the physical breaks of the two regions were coincident in point of time (that is, that the mountain-making movement which preceded the deposition of the Potsdam sandstone of the Lake Superior country corresponded with that which preceded the Tonto sandstone of the Grand Cañon region); that the mountain-making periods preceding the deposition of the Grand Cañon series of the Grand Cañon district and of the Keweenaw series of the Lake Superior region were equally synchronous; and, finally, that the Grand Cañon series is, in general, the equivalent of the Keweenaw series, while the Pre-Grand Cañon rocks are the equivalent of the Lake Superior Huronian.

Of course such correlations as these should be made, for the present at least, somewhat provisionally; but, on the other hand, they must be taken as of much greater value than correlations between distant formations established on feeble fossil evidence. The correlations between the periods of mountain-making movement in the different districts in such a case are, of course, more likely to be approximations to the truth than the correlations between the formations separated by such mountain-making periods. The Pre-Grand Cañon quartzitic series, for instance—while we may with some reason parallelize its disturbance with that of the Lake Superior Huronian—may itself correspond to part or all of that group or be entirely anterior or subsequent to it, corresponding then to a portion either of the time gap which follows the Huronian or of that which precedes it.

A question of yet greater importance is that with regard to the attention to be paid to unconformities in making correlations with the general geological column. For instance, in the case of the Lake Superior formations, in which the lowest of the distinct fossiliferous horizons is the Potsdam sandstone of the Cambrian, are we to count

as Cambrian any or all of the formations which unconformably underlie that sandstone? We have already seen that beneath this sandstone there lie in this region three great series of rocks, each separated from its predecessor by one of the greatest of discordances. Is the term Cambrian to stop at the first unconformity below the Potsdam sandstone? Is it to extend to the second of these unconformities or to the third? Or is it to include, finally, the lowest of the formations of the region?

All these usages of the term have been made. In taxonomical value the term Cambrian is designed, of course, to correspond to the terms Upper Silurian, Lower Silurian, Devonian, Carboniferous, etc., which terms are based primarily upon the general continuity, for each one of the periods to which they correspond, of similar life conditions. In no case, however, has one of these terms been allowed to span any such unconformable break as the least of those beneath the Potsdam sandstone of the Lake Superior region. Minor breaks in the succession have been included within a single one of these geological groups because—although in every case of a physical break, even the smallest, a corresponding break in life-succession is found—there have been found on both sides of the break fully developed faunas of general similarity in characters; but no great break in the succession such as those with which we are now concerned has ever yet been found to be spanned by a continuity of forms. The conclusion, therefore, seems inevitable that we should not extend the term Cambrian over any such break, at least until there shall have been found closely corresponding faunas on opposite sides of the interval. Were such faunas to be discovered the greatness of the unrecorded interval would still remain and we should have indicated only a singularly long continuance of similar life-conditions. Even then the question might arise as to whether continuity of life-conditions should outweigh the great lapse of time indicated by the physical hiatus.

SUMMARY OF CONCLUSIONS.

In classifying the earlier clastic formations of the geological series their *paleontological characters* are properly used—

(1) *To separate the groups of a given region* when the fully developed faunas of contiguous groups present strong contrasts, looked at in their entireties.

(2) *To collect several contiguous formations in a single group* when the well developed faunas of these formations present such strong similarities as to indicate in a general way a continuity of life conditions.

(3) *To correlate the groups and formations of one portion of a single geological basin with those of another portion of the same basin* when the faunas are well developed and the correlations are not

CONGLOMERATE OF OGISHKIMANISSI LAKE, NORTHERN MINNESOTA.

extended to the minor subdivisions without strong accompanying physical evidence.

(4) *To establish correlations between the groups of different basins* when the similarities of the faunas compared are not confined to a single fossil type or to but few fossil types, but extend throughout the abundant and varied faunas.

They are improperly used—

(1) *To assign to different groups the formations of a given region, without strong accompanying physical evidence*, when the faunas of the supposed distinct groups are not sufficiently contrasted, when one group has a fully developed fauna and the next is nearly or quite barren, or when both groups have but meagerly developed and uncharacteristic faunas.

(2) *To place several formations in a single group* when the similarities between the fossils of the two formations so placed together are confined to a few forms of wholly uncertain range and when such similarities are used to outweigh strong physical evidence of separateness.

(3) *To correlate the groups and formations of different portions of a single geological basin* when the correlations are extended to the minor subdivisions of the groups on the strength of assumed vertical ranges of the species employed and when such correlations between minor subdivisions are presented without confirmatory stratigraphical, lithological, and structural evidence, or when they are pushed in the face of such evidence.

(4) *To establish general correlations* when such correlations are based upon meagerly developed faunas or upon a few obscure forms belonging to types of great vertical range.

Lithological characters are properly used in classification—

(1) *To place adjacent formations in different groups, on account of their lithological dissimilarities* when such dissimilarities are plainly the result of great alteration in the lower one of the two formations and are not contradicted by structural evidence, or, if used as confirmatory evidence only, when such dissimilarities are the result of original depositional conditions.

(2) *To collect together in a single group adjacent formations because of lithological similarities* when such similarities are used as confirmatory evidence only.

(3) *To correlate groups and formations of different parts of a single geological basin* when such correlations are checked by stratigraphy and particularly by observations made at numerous points between the successions correlated.

They are improperly used—

(1) *To place adjacent formations in different groups, on account of lithological dissimilarities* when such dissimilarities are merely the result of differences in original depositional conditions and when such

evidence of distinction is not confirmed by or is contradicted by structural and paleontological evidence.

(2) *To collect in a single group adjacent formations because of lithological similarities* when such similarities are not confirmed by or are contradicted by other evidence.

(3) *To establish general correlations between the clastic groups of different geological basins,* except possibly when the gneissic and true crystalline-schist basement formation of one region is compared with the similar basement formation of another.

(4) *To establish and determine any world-wide subdivisions of the non-eruptive basement crystallines*—i. e., those which underlie the clastic groups here called Huronian—at least until very much more definite evidence of the existence of such subdivisions be gathered than has hitherto been done.

The structural breaks called unconformities are properly used in classification:

(1) *To mark the boundaries of the rock groups of a given region.*

(2) *To aid in establishing correlations between the formations of different parts of a single geological basin.*

(3) *To aid in the establishment of correlations between the groups of regions distantly removed from one another;* but caution is needed in attempting such correlations in proportion as the distances between the regions compared grow greater.

They are improperly ignored:

(1) *When the evidence they offer as to separateness is allowed to be overborne* by anything but the most complete and weighty of paleontological evidence.

TAXONOMY OF THE LOWER PART OF THE GEOLOGICAL COLUMN.

In the Lake Superior regions then, if the preceding arguments and conclusions be accepted as valid, we have, beneath the Cambrian horizon and above the gneissic basement formation, two great terranes, each of which is entitled, by its enormous thickness of strata and by the immense natural physical breaks between it and the adjacent formations above and beneath, to a taxonomical position fully equal to that assigned to the entire Cambrian group.

According to the nomenclature that has been proposed by the U. S. Geological Survey, the clastic rock masses of the earth's surface are classified in three orders of magnitude, viz. the *system,* the *group,* and the *formation.* The most comprehensive of these three classes is the *system,* which term it is designed to apply to the great divisions of the geological section defined by paleontology and recognizable the world over. Such are the Cenozoic, Mesozoic, and Paleozoic systems. Next in order comes the *group,* which it is designed to apply to those great divisions of the systems which are based mainly

upon paleontological distinctions, but also upon structural separateness, and only very subordinately upon petrography. These groups are recognizable in various countries; they are presumptively world-wide in their distribution, and they appear to approach an equality in volume. Such are the Carboniferous, Devonian, Silurian, and Cambrian groups. These divisions are groups in the sense that they commonly include a number of subordinate members distinguishable from one another petrographically, genetically, and even paleontologically. These subordinate members finally are the *formations* of this system of nomenclature, though the term formation is also used with a vaguer signification, to cover any rock mass whose distinction from surrounding masses is desirable on one ground or another.

This classification applies, as said before, to the clastic groups only. Outside of these are the eruptive and non-eruptive crystalline rocks. Those last named, however, naturally have not been classified in systems, groups, etc. by the U. S. Geological Survey, because of the doubts as to their origin and as to their structural positions with reference to the clastic groups. Some of them are very plainly beneath all of the regular clastic strata, while others are of disputed position, some geological writers holding that they also belong beneath all clastic groups, while others regard them as altered representatives of these groups at various positions in the geological column.

Now, in such a classification the Keweenawan and Huronian series of strata are certainly entitled to the rank of groups. They are so entitled (1) because, notwithstanding they include a considerable content of volcanic crystallines, they are nevertheless in the main made up of genuine sedimentary strata, whose formation by the same processes which have been at work in the accumulation of later sedimentaries is easily demonstrable; (2) because they have accumulated during the existence of life on the globe, as hereafter maintained; (3) because of their great volumes, which are not only comparable with, but very considerably exceed those of, the ordinary rock groups; (4) because they are divisible into subordinate members which are in turn fully entitled to the rank of formations; (5) because of their entire structural separateness from the oldest of the groups above them, from each other, and from the crystalline basement rocks below them; and, finally, (6) because of their presumptively wide extent.

Conditions similar to those of the Lake Superior region recur in the Grand Cañon of the Colorado and probably also in central Texas. In Newfoundland, again, we have unconformably placed beneath the Cambrian, here developed with an enormous thickness and down to its lowest known fossiliferous horizons, two mutually discordant series, the upper one of which is entitled on the principles advocated in this paper to full recognition as a clastic group, while the lower

one is crystalline and gneissic. In numerous other regions similar conditions have been more or less distinctly made out; but the geological column, as it is now ordinarily presented, provides beneath the Cambrian for one great division only—the Archæan. By some authors this Archæan is recognized as divisible into Huronian and Laurentian; but very few writers, even when they have recognized the independent existence of Pre-Cambrian and Post-Laurentian groups, seem to have accorded to such groups the taxonomical rank to which they are entitled. Certainly there has been no general recognition of these groups, such as would lead to the provision for them of a proper place in the general geological column. But in view of the facts summarized in this paper and of those which have been accumulated by various workers in different portions of the world, it is evident that some such provision should be made.

In attempting to make the required modification of the geological column, a most important question presents itself for settlement at the very outset. If we suppose it agreed that all clastic formations now known and to be discovered in the future which unconformably underlie the Cambrian are to be thrown out of the Cambrian group, it immediately becomes necessary to inquire whether the new groups, which must be established to hold these formations, are to be regarded as Paleozoic. Four different answers to this inquiry may be made, all but the last of which as here given have been more or less distinctly presented heretofore. We may regard all as Archæan; we may carry the term Paleozoic to the break between the Keweenaw series and the Huronian; we may restrict the term Archæan to the gneissic basement series; and, finally, we may introduce some entirely new term of equal rank with Paleozoic and Archæan to cover the formations between the gneissic series and the Cambrian.

In deciding between these different positions we can take cognizance (1) of the apparent relative extents of the time intervals between these several groups and (2) of the indications presented by them of the existence or absence of life during their deposition.

The evidence under each one of these heads favors very strongly the restriction of the term Archæan to the gneissic basement terrane. The time interval between that series and the Huronian next above it was far greater than that indicated by any of the higher unconformities with which we are concerned. That this interval was so great is indicated in the first place by the relative degrees of alteration which these two series have undergone. The Huronian—i. e., that series to which the term Huronian is restricted in this paper—is, in the main, a fragmental formation, such alterations as have taken place in it being of the nature of interstitial additions to the original fragments or of minor metasomatic changes. It is essentially a clastic, and not a crystalline-schist, series. The basement terrane, or Laurentian, however, exhibits a complete crystalline development, without any or at least extremely rare traces of frag-

mental constitution, and is a genuine crystalline-schist series. With the exception of portions of its granitic masses, evidently eruptive among other rocks of the series, all of its members, whether originally of igneous or of sedimentary origin, have been most intensely modified by pressure and recrystallization. Only rarely can a trace of a former fragmental nature be detected. Basic igneous rocks have been converted by pressure into a whole series of chloritic, hornblendic, and augitic schists. Acidic eruptives have been converted into gneisses, mica-schists, sericitic schists, felsitic schists, etc. Again, the amount of disturbance that the gneissic formation underwent prior to the deposition of the Huronian entirely outweighs that received by the Huronian since, while the amount of denudation of the Pre-Huronian land surface as compared with that which followed the Huronian was immensely greater.

As to indications of the existence of life during the deposition of these several Pre-Cambrian groups, it may be said that we have no satisfactory evidence of its existence previous to the time of deposition of the Huronian. That it existed plentifully when the Huronian group was accumulating is plainly indicated, not only by the force of the general argument based upon the high development of life at the beginning of the Cambrian and its consequent necessary existence for great periods prior to that time nor yet by the occasional discovery of obscure fossil remains, but by the abundant occurrence, in this group, of shales and slates filled with organic matter and of extended ferruginous strata whose original accumulation was certainly dependent upon the existence of organic matter. That the carbon of the abundant black shales is matter of genuine organic origin and an original ingredient, and not merely a chemically deposited graphite or a graphite introduced during a subsequent metamorphism, is rendered entirely evident by residual traces of hydrocarbons and by chemical analysis as well as by a close study of thin sections of the rocks, which show the carbonaceous substance they contain to be entirely similar in character and occurrence to that contained in the carbonaceous shales of all later formations, in which cases its organic origin has never been questioned. It has been assumed by some writers, who have opposed any view maintaining the existence of life during the accumulation of these ancient formations, that the only form of carbon found in them is the graphitic form, which, being producible, as is well known, by other than organic agencies, is taken to be no indication of the existence of life during the time of deposition of the rocks in which it is found. But in the case of the Huronian the graphitic form is unusual, and when it occurs it is plainly merely a phase of the ordinary black, carbonaceous matter of the carbonaceous shales. Moreover that organic matter was concerned in the original accumulation of the great iron horizons of the Huronian is a conclusion not reached by a purely theoretical comparison of these horizons with the iron horizons

of later times, as the Carboniferous for instance, but is shown by the abundant visible occurrence of such organic matter in these iron horizons themselves, whose present developments have been conclusively shown, from a study of field conditions and of hundreds of thin sections, to have been, in large measure, the result of a silicification of beds closely comparable with the Coal Measure iron carbonates.[1] Carbonate of iron and organic matter are constant associates, and there was in the Huronian quite as much of both as in any of the latter groups except the Carboniferous.

Finally, we may cite in favor of a restriction of the term Archæan to the Pre-Huronian basement formation the general tendency, among those geologists who have made the most extensive studies of the crystalline basement schists, to the view that the exact conditions which gave rise to them have never been repeated in later geological time.

It seems desirable to restrict the term Archæan to the basement crystallines, because of the greatness of the time interval between that series and the next succeeding it, in comparison with any of the later interruptions of the geological column; because of its intensely altered condition and generally unique characteristics, as compared with those of any of the later groups; and because of the lack of definite evidence of the existence of life during its production, while life plainly existed at the time of the deposition of the earliest of the succeeding groups. But it is not so evident that we should extend the term Paleozoic over the rocks which this restriction would throw out from the Archæan and over those newly established groups which intervene between the Cambrian and the Archæan as heretofore recognized. If the term Paleozoic is to be used to cover all formations accumulated after the beginning of the existence of life on the globe we should, of course, extend it downward over the groups in question. But such is certainly not its ordinary use, inasmuch as it is commonly applied to a grand life system which, while progressive from the earliest Cambrian to the latest Carboniferous, is, nevertheless, a coherent whole when compared with the later Mesozoic and Cenozoic life systems. It may be that future discoveries of fossils among the Pre-Cambrian and Post-Archæan formations will develop the fact that the genuine Paleozoic life extended over the times of their accumulation also, but at present we have no means of deciding as to this, and it seems that we might, not improperly, make use of some term of equal taxonomic value with Archæan and Paleozoic with which to cover all Pre-Cambrian and Post-Archæan formations yet discovered or to be discovered. I say to be discovered, because there is no reason to suppose that there are but two groups of strata between the Archæan and the Cambrian. The time intervals indicated by the unconformities between the groups already

[1] Origin of the ferruginous schists and iron ores of the Lake Superior region: Am. Jour. Sci., 3d series, vol. 32, 1886, p. 255.

discovered as belonging to this interval and between them and the Cambrian on one side and the Laurentian on the other are such as to suggest the probability of the existence somewhere in the geologically unknown portions of the world of other grand groups of Pre-Cambrian strata. That such groups will be discovered in the future and that life systems will be made out for them, imperfect to be sure, the whole past history of paleontological discovery and advance justifies us in expecting. Few persons who have not had their attention particularly drawn to the matter realize what extensive portions of the earth's surface are as yet geologically terræ incognitæ. Such an arrangement as this would have the especial advantage that it would furnish us with a term to cover any strata found anywhere in the world to belong in the interval between the Cambrian and Archæan without forcing us to classify them more minutely. As has already been seen, as long as these Pre-Cambrian strata have failed to furnish us any characteristic faunas, we must be at fault in attempting to correlate with one another the Pre-Cambrian groups of widely separated regions.

It may be thought that the same advantage could be obtained by using some one term in the group column of the geological classification to cover all such known and as yet unknown groups; in which case the term Paleozoic would extend downward over all groups save the basement gneisses. The objection to this arrangement would be that it would relegate such great series of strata as the Huronian and Keweenawan to the formation column; whereas, while paleontological evidence as to their title to rank as groups fails, in all other respects these two grand series of strata are fully entitled to rank with the greater geological groups, with which they more than compare in thickness and in the lengths of the time intervals by which they are separated from each other and from the preceding and succeeding divisions. Were the paleontological evidence forthcoming it is to be expected that it would confirm the right to this high rank indicated by the physical evidence.

The Carbonaceous shales (bearing traces of hydrocarbons), the associated iron carbonates, and the lime carbonates which form great members of the Huronian series constitute sufficient evidence of the existence of life to place these groups within the zoic series. They do not, however, show sufficiently definite traces of distinct forms of life to justify the assertion that it was of the character of that to which the term Paleozoic has been applied. It seems, therefore, desirable that a new term should be introduced of equal classificatory rank with Paleozoic, indicating that these great Pre-Cambrian and Post-Archæan series are zoic in character and that they cannot, as yet at least, be admitted to the Paleozoic series proper. In an article in the American Journal of Science for 1887 (page 373), I advocated the adoption of the term Agnotozoic (ἄγνωτος, unknown; ζωή,

life), indicating at once the presence of life and its unknown character.[1] A recognized objection to this term may be based upon the consideration that if definite faunas shall be discovered in these formations or in any of them the term Agnotozoic would be inapplicable. To this it may be replied that it is improbable that such discoveries will be made in all of the formations included under this term and that it will still be needed for the residue. If definite faunas are found in any of them and these prove to be Paleozoic in character, the formation containing them will simply be transferred to the Paleozoic series and the remainder of the formations left under the term Agnotozoic. If, on the other hand, the faunas prove to be diverse from the Paleozoic, a new zoic group bearing a name appropriate to the discovered life will be required in any case, whether the term Agnotozoic or any other imaginable term be now applied to the formation.

Some of my colleagues upon the survey, however, prefer the more non-committal term Eparchæan, signifying simply the position of these formations upon the Archæan. To this term the same objection applies as to the preceding, that the discovery of a definite fauna would necessarily call for an appropriate zoic classification, under the canons of good nomenclature. In short, it may be safely remarked that, while there is an imperative demand for a separate term adapted to the present needs of the science, any term now proposed must be held subject to future limitation or entire replacement, if any sufficiently distinctive paleontological discoveries shall be made.

The following table shows the arrangement of formations suggested, in which the terms Agnotozoic and Eparchæan are both introduced:

Systems.	*Groups.*	*Systems.*
Paleozoic.	Carboniferous.	Paleozoic.
	Devonian.	
	Silurian.	
	Cambrian (Lower Silurian)	
Agnotozoic or Eparchæan.	Keweenawan.	
	Huronian.	
	(other groups ?)	
Archæan.	Laurentian (including Upper Laurentian).	Archæan.

[1] See, also, Note respecting the term Agnotozoic, by T. C. Chamberlin: Am. Jour. Sci., 3d series, vol. 35, 1888, p. 254.

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